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SECTION—A

PART V

PROCEEDINGS
OF
THE SYMPOSIUM
ON
RECENT TRENDS IN SOIL
RESEARCH
PART V

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THE SYMPOSIUM
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PART V

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SECTION—5

SOIL MICROBIOLOGY

EFFECT OF PHOSPHATES AND TRACE-ELEMENTS (MOLYBDENUM,
VANADIUM, BORON AND ARSENIC) ON THE MICROBIAL
POPULATION OF A SOIL IN RELATION TO THE
PHENOMENON OF NITROGEN FIXATION

By

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(Received on 3rd December, 1954)

Recently Dhar and coworkers¹ have reported that the presence of phosphates, especially as calcium phosphates, enhance nitrogen fixation markedly. The efficiency of such a process *i.e.*, the amount of nitrogen fixed in milligrams per gram of carbon oxidized is much greater than that without phosphates. They have therefore, concluded that phosphate-rich soils can be rich in nitrogen.¹ It is also well-known that phosphate is one of the essential requisites of cell-protoplasm² and as such it is essential for the proper growth of all living bodies including the micro-organisms like bacteria. We have, therefore, investigated the importance of phosphates on the growth of bacteria as also on the fixation of nitrogen.

The trace-elements, or the "minor elements" as they are often called, have so far been associated with the problem of plant pathology. Various trace-elements have been used as a measure to detect and rectify a particular type of disease affecting a good crop. Only a few have tried to study the effect of these substances either on the bacterial numbers or on the nitrogen status of the soil. Some have recently claimed the importance of molybdenum for the nodule-

bacteria or Rhizobia³ while some others have claimed its beneficial effect on the proper functioning of Azotobacter cells. Hence, along with the role of phosphates we have studied the effect of trace-elements like molybdenum, vanadium, boron and arsenic on the phenomenon of nitrogen fixation as well as on the bacterial numbers.

EXPERIMENTAL

In carrying out the experiment 200 gms of a sample of soil were made to pass through a standard 80 mesh sieve and taken, in duplicate, in a number of shallow enamel plates of 16 cm diameter. To each of these plates a known amount of sucrose (energy-material), corresponding to 0.5% carbon, was added. In some of these plates 0.05% P_2O_5 was added in the form of the following phosphates :—

Monocalcium phosphate [$CaH_4(PO_4)_2 \cdot H_2O$], dicalcium phosphate ($CaHPO_4 \cdot 2H_2O$), tricalcium phosphate [$Ca_3(PO_4)_2$], aluminium phosphate ($AlPO_4 \cdot H_2O$) and ferric phosphate ($FePO_4$). In one of the sets 1% KCl was added along with $Ca_3(PO_4)_2$ to study the effect of organic matter + P_2O_5 + K.

In the remainder of the plates calculated amounts of $Na_2MoO_4 \cdot 12H_2O$, $Na_3VO_4 \cdot 12H_2O$, $Na_2B_4O_7 \cdot 10H_2O$ and $Na_2HAsO_4 \cdot 12H_2O$ corresponding to 0.05% MoO_3 , 0.05% V_2O_5 , 0.05% B_2O_3 and 0.05% As_2O_5 respectively were added separately so that each plate received only one of these trace-elements. A control set was also started without using any of these added materials except sucrose. The moisture was maintained at 20% by adding measured quantities of distilled water and the mixture was stirred every alternate day to ensure uniform aeration. One of the sets was exposed to light from a 60 watt electric bulb placed at a distance of 3 feet above the table while the other set was covered with a black cloth. Samples were taken out from time to time and analysis for the carbon and nitrogen were made after carefully drying in an air-oven. A portion of the sample was kept aside for bacteriological studies before putting the soil in the oven. Estimations for total organic carbon were carried on according to Walkley and Black's method of rapid titration.⁴ Total nitrogen of the system was estimated by the Kjeldhal method using the salicylic acid reduction modification.⁵

Bacteriological counts were made for total bacteria and Azotobacter by strictly following the silica-gel technique of Waksman and Fred.⁶ Silica-gel was prepared using Thornton's medium for total bacteria and Beijerinck's medium for Azotobacter counts. For the counting purposes plating technique was followed and always an average of 4 plates were taken. The silica-gel is highly selective in nature and the errors due to contamination are considerably minimised allowing that particular organism to grow for which a medium has been used. This allows a fair to excellent growth of the bacteria concerned. The total bacteria included the actinomycetes and not fungi. The plates were incubated at 35°C for 72 hours before counting was done. The Azotobacter colonies appeared as viscid oval or round colonies which usually gave a tinge of brownish to black colour on ageing indicating the presence of the pigment which is characteristic of the species Azotobacter chroococcum. Microscopic observations were made from time to time in the case of doubtful colonies as well as to observe any morphological changes appearing in the individual cells. Azotobacter cells were found to be larger than majority of bacteria and varied from rod to spherical shape, though round or oval types generally predominated.⁷

Before starting the experiments the soil was carefully analysed for its bacterial numbers and chemical constituents which appear in the following table:—

TABLE No. I

Analysis of normal soil passed through 80 mesh sieve

Chemical analysis (oven-dry basis)		Bacterial numbers (air-dry basis)	
Constituents	Composition	Bacterial analysis	Millions per gm. of dry soil
Loss on ignition	3.7550%	Total bacteria	25
HCl insoluble	81.6524%	Azotobacter	4.5
Sesquioxides	11.1650%	Fungi	0.5
Fe O ₃	4.1300%		
CaO	0.9893%		
MgO	1.1570%		
P ₂ O ₅	0.0785%		
K ₂ O	0.7328%		
Exchangeable calcium (Ammonium acetate soluble)	22.3 m.e/100		
Available P ₂ O ₅ (1% citric acid soluble)	0.0314%		
Total organic carbon	0.4680%	} C/N ratio = 10.1	
Total nitrogen	0.0462%		
NH ₄ —N	0.0041%		
NO ₃ —N	0.0109%		
pH	7.6		

The energy material and the phosphates were tested for their purity before addition. The energy material, *i.e.*, sucrose was analysed for its carbon and Nitrogen content:—

Analysis of Sucrose

Total carbon 41.4%

Total nitrogen 0.00045%

The results of the above experiments with phosphates have been recorded in the following tables:—

TABLE No. 2 (a)

Light

Average temperature 27.5°C

200 gms Normal soil + 0.5% Carbon (added as sucrose) (Control)

Days	Total carbon %	Total Nitrogen %	Carbon oxidized %	Change in total N ₂ %	Efficiency	Total bacteria millions/gm	Azotobacter millions/gm
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.6356	0.0586	0.3214	+0.0119	37.0	30.0	6.2
90	0.6125	0.0584	0.3445	+0.0117	33.9	28.5	5.7

TABLE No. 2 (b)

<i>Dark</i>							
Days	Total carbon %	Total Nitrogen %	Carbon oxidized %	Change in total N ₂ %	Efficiency	Total bacteria millions/gm	Azotobacter millions/gm
0	0.9570	0.0467	...	...	..	25.0	4.5
60	0.6865	0.0524	0.2705	+0.0057	21.0	70.5	12.4
90	0.6354	0.0520	0.3216	+0.0053	16.4	65.7	10.2

TABLE No. 3 (a)

<i>Light</i>						Average temperature 27.5°C	
	200 gms soil + 0.5% C + 0.05% P ₂ O ₅ [as CaH ₄ (PO ₄) ₂ ·H ₂ O]						
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.6030	0.0646	0.3540	+0.0179	50.5	52.0	8.6
90	0.5820	0.0640	0.3750	+0.0173	46.1	46.0	7.1

TABLE No. 3 (b)

<i>Dark</i>							
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.6315	0.0570	0.3255	+0.0103	31.6	97.5	16.0
90	0.6095	0.0565	0.3475	+0.0098	28.2	93.0	14.0

TABLE No. 4 (a)

<i>Light</i>						Average temperature 27.5°C	
	200 gms soil + 0.5% C + 0.05% P ₂ O ₅ (as CaHPO ₄ ·2H ₂ O)						
0	0.9570	0.0467	...	...	...	25.0	4.9
60	0.6005	0.0670	0.3565	+0.0203	56.9	60.0	9.0
90	0.5725	0.0660	0.3845	+0.0193	50.1	58.0	8.1

TABLE No. 4 (b)

<i>Dark</i>							
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.6300	0.0592	0.3270	+0.0125	38.2	129.5	27.8
90	0.6156	0.0582	0.3414	+0.0115	33.7	120.0	24.9

TABLE No. 5 (a)

<i>Light</i>						Average temperature 27.5°C	
	200 gms soil + 0.5% C + 0.05% P ₂ O ₅ [as Ca ₃ (PO ₄) ₂]						
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.5985	0.0700	0.3585	+0.0233	64.9	53.0	8.4
90	0.5680	0.0698	0.3890	+0.0231	59.3	47.0	7.0

TABLE No. 5 (b)

<i>Dark</i>							
0	0.9570	0.0467	...	...	...	25.0	4.5
60	0.6278	0.0620	0.3292	+0.0153	46.4	112.7	14.3
90	0.6121	0.0614	0.3449	+0.0147	42.6	95.0	12.5

TABLE No. 6 (a)

Light

Average temperature 27.5°C

200 gms soil + 0.5% C + 0.05% P₂O₅ (as AlPO₄·H₂O)

Days	Total C %	Total N ₂ %	Carbon oxidized %	Change in total N ₂ %	Efficiency	Total bacteria millions/gm	Azotobacter millions/ gm
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.5640	0.0541	0.3930	+0.0174	44.2	28.0	4.9
90	0.5452	0.0636	0.4118	+0.0169	41.0	26.9	4.7

TABLE No. 6 (b)

Dark

0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.5940	0.0567	0.3630	+0.0100	27.5	65.0	11.8
90	0.5790	0.0560	0.3780	+0.0093	24.6	50.5	8.5

TABLE No. 7 (a)

Light

Average temperature 27.5°C

200 gms soil + 0.5% C + 0.05% P₂O₅ (as FePO₄)

0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.5340	0.0664	0.4230	+0.0197	46.5	35.0	6.5
90	0.5190	0.0660	0.4380	+0.0193	44.0	32.0	5.9

TABLE No. 7 (b)

Dark

0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.5550	0.0600	0.4020	+0.0133	33.0	87.1	12.5
90	0.5340	0.0592	0.4230	+0.0125	29.5	80.5	10.7

TABLE No. 8 (a)

Light

Average temperature 27.5°C

200 gms soil + 0.5% C + 0.05% P₂O₅ [as Ca₃(PO₄)₂] + 1% KCl

0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.5640	0.0744	0.3930	+0.0277	70.4	57.5	9.1
90	0.5490	0.0730	0.4080	+0.0263	64.4	50.4	8.2

TABLE No. 8 (b)

Dark

0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6060	0.0641	0.3510	+0.0174	49.5	128.6	28.6
90	0.5790	0.0634	0.3780	+0.0167	44.1	125.0	25.7

The results obtained on the experiments with the same soil carried on in presence of trace-elements have been recorded in the following table :—

TABLE No. 9 (a)

<i>Light</i>		Average temperature 27.5°C					
200 gms soil + 0.5%C + 0.05% MoO ₃ (as Na ₂ MoO ₄ ·12H ₂ O)							
Days	Total C %	Total N ₂ %	Carbon oxidized %	Change in Total N ₂ %	Efficiency	Total Bacteria millions/gm	Azotobacter millions/gm
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6325	0.0647	0.3245	+0.0180	55.4	56.0	9.7
90	0.5984	0.0640	0.3586	+0.0173	48.2	50.0	8.2

TABLE No. 9 (b)

<i>Dark</i>							
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6425	0.0582	0.3145	+0.0115	36.5	98.0	17.7
90	0.6264	0.0580	0.3306	+0.0113	34.1	94.8	14.5

TABLE No. 10 (a)

<i>Light</i>		Average temperature 27.5°C					
200 gms soil + 0.5% C + 0.05% V ₂ O ₅ (as Na ₃ VO ₄ ·12H ₂ O)							
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6202	0.0630	0.3368	+0.0163	48.4	28.2	5.0
90	0.5962	0.0627	0.3608	+0.0160	44.3	27.0	4.7

TABLE No. 10 (b)

<i>Dark</i>							
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6398	0.0565	0.3172	+0.0098	30.8	62.0	10.9
90	0.6227	0.0560	0.3343	+0.0093	27.8	57.5	9.9

TABLE No. 11 (a)

Light		Average temperature 27.5°C					
200 gms soil + 0.5% C + 0.5% As ₂ O ₅ (as Na ₂ HAsO ₄ ·12H ₂ O)							
0	0.9570	0.0467	—	—	—	25.0	0.5
6	0.6250	0.0636	0.3320	+0.0169	10.9	3.1	0.21
90	0.5975	0.0634	0.3595	+0.0167	46.4	1.5	0.08

TABLE No. 11 (b)

<i>Dark</i>							
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6415	0.0572	0.3155	+0.0105	33.2	5.4	0.50
90	0.6252	0.0568	0.3318	+0.0101	30.4	2.8	0.12

TABLE No. 12 (a)

Average temperature 27.5°C

*Light*200 gms soil + 0.5% C + 0.05% B₂O₃ (as Na₂B₄O₇·10H₂O)

Days	Total C %	Total N ₂ %	Carbon oxidized %	Change in Total N ₂ %	Efficiency	Total Bacteria millions/ gm	Azotobacter millions/gm
0	0.9570	0.0467	—	—	—	25.0	4.5
60	0.6180	0.0605	0.3330	+0.0138	40.7	26.5	4.8
90	0.5640	0.0598	0.3930	+0.0131	33.3	26.0	4.6

TABLE No. 12 (b)

Dark

0	0.9570	0.0467	—	—	—	25.0	5.5
60	0.6360	0.0565	0.3210	+0.0098	30.5	52.8	10.7
90	0.6060	0.0560	0.3510	+0.0093	26.4	48.6	8.2

DISCUSSION

From the foregoing data it is observed that the bacterial response is quite pronounced in the plates to which phosphates were added in the form of calcium phosphates. Both calcium as well as phosphate are essential for the multiplication and growth of the bacterial cell and that is probably the reason why the phosphate effect on the bacterial number differ considerably when aluminium phosphate and ferric phosphate have been added. There is appreciable increase in numbers with ferric phosphate because iron is also one of the essential requirements, but only in small amounts, for the proper functioning of the cell-protoplasm. Our results clearly show that aluminium phosphate is definitely harmful to the bacteria and there can be no doubt that it exerts a toxic effect. The bacterial figure with aluminium phosphate is even lower than that obtained with control.

There is marked difference in bacterial response towards the three different varieties of calcium phosphate used. The most probable reason for this difference must be due to the pH effect. Azotobacter as well as total bacteria, being living organisms, are considerably affected by the pH changes as the cell-protoplasm is extremely susceptible towards pH variations. It is generally well-known that Azotobacter prefers a slightly alkaline medium for its proper functioning. Probably the ideal pH for it ranges between 7.3 to 7.8 though it can grow within the pH range 6.0 to 7.8. It rarely occurs at a pH below 6.0.⁸ Monocalcium phosphate is an acidic substance and as such when added to the soil it brings down the pH below 7.0. Though it is well-known that it undergoes transformation to the dicalcium variety when added to a soil but it does not seem to help in any way the bacterial growth. Apparently the acidity, which it exerts at the initial stage, damages the growth. An almost similar effect can be observed with the tricalcium phosphate used. Here the problem is not that of acidity but it is of alkalinity. Tricalcium phosphate is considerably alkaline and when added to a soil can increase the pH to show a marked degree of alkalinity. The bacterial cell seems to be sensitive towards alkalinity. There has not been much bacterial response towards tricalcium phosphate though it seems to be better in comparison to monocalcium phosphate.

Dicalcium phosphate, on the other hand, seems to be the ideal phosphatic food for bacterial growth. This substance is known to exert a buffer effect and

thus save the soil from becoming either too acidic or too alkaline which is the ideal condition for the functioning of living organisms. Its solubility increases in H_2CO_3 and other weak organic acids which are present in the soils to which organic matter has been added. By far the best growth of *Azotobacter* was observed in the plate to which a mixture of $Ca_3(PO_4)_2$ and 1% KCl was added along with the energy-material. *Azotobacter* needs some K along with calcium and phosphate.

The results obtained with the trace-elements show that the response of bacteria towards the individual trace-element differ considerably. Molybdenum causes a fair growth of bacteria whereas, boron and arsenic retard their growth. With arsenic there is a sharp fall in their numbers. Arsenic has been recognised for a long time as a poison for any living form. Vanadium can support bacterial growth but it does not seem to be so effective as molybdenum.

The nitrogen fixation in all these experiments increase with the increase in the bacterial number except in the case of arsenic. But the most interesting thing evident from the tables is that there is always more nitrogen fixed in the case of plates exposed to artificial light though the bacterial number is almost double in the dark counterparts of the same plates. More especially, in the case of arsenic, it can be observed that there is nitrogen fixation taking place even without the active support of the bacteria which are on a decline there. Here again, the effect of light is considerable so far as nitrogen fixation is concerned. Thus, the increase in the bacterial figure does not substantially help much in the nitrogen fixation process and the difference observed in the case of light and dark experiments cannot be explained from the biological view point because light is definitely known to be harmful for the bacteria.

The above results and the conclusions drawn thereof lead us to believe that nitrogen fixation process may not be wholly a phenomenon arising out of bacterial activities. Also we conclude from the aforesaid experimental results that phosphates and trace-elements, especially molybdenum, considerably help in this process. For all agricultural practices therefore, we would recommend the use of calcium phosphates along with organic substances, a little potash and a little of trace-elements as substitutes for any artificial manure as the former retain their manurial value for a much longer period.

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ON NITROGEN LOSS DURING NITRIFICATION IN CULTURES OF NITRIFYING ORGANISMS

By

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(Received on 14th December, 1954)

The importance of nitrates to the plant and of nitrification to soil fertility has now become a well recognised fact due to the investigations of Schloesing, and Muntz,¹ Warington,² and Winogradsky,³ asserted that nitrification was mainly a biological phenomenon and finally isolated the two groups of bacteria responsible for nitrification, each one of which was found to be narrowly specific in its action.

In order to demonstrate the essential facts of nitrification Russell⁴ has stated as follows :—

“The essential facts of nitrification are readily demonstrated by putting a small quantity of soil (0.2—0.5 gm) into 50 ml of a dilute solution of ammonium sulphate containing nutrient inorganic salts and some calcium and magnesium carbonates but no other carbon compound. After three or four weeks at 25°C, the ammonia is all gone and its place is taken up by nitrates. The conversion is almost quantitative, only an insignificant quantity being retained by the organisms.”

Russell⁵ has also stated the problem of bacterial production of nitrates in the following words :—

“Nitrate production is confined to one or two organisms only at each stage and the end result is a single product quantitatively equivalent to the original ammonia ; no single chemical process oxidizes ammonia in this complete manner.”

But at the same time actual field observations at Rothamsted⁶ have shown that when 100 lbs of nitrogen per acre are added, about 65% is lost without benefit to the soil or the crop. Marked losses of nitrogen during the nitrification of organic and inorganic nitrogenous manure have also been recorded by Dhar and co-workers⁹⁻¹³ in several previous publications.

Hence in order to explain the difference in these observations and to study whether a similar loss of nitrogen also occurs during the bacterial nitrification of ammonium salts, some experiments have been performed with enriched cultures of nitrite and nitrate forming bacteria.

EXPERIMENTAL

An enriched culture of nitrite forming bacteria was prepared from garden soil by Omeliansky's method of bacterial culture, the medium employed being :—

MEDIUM I. Ammonium sulphate	(NH ₄) ₂ SO ₄ . . .	2.5 gm
Pot. phosphate	K ₂ HPO ₄ . . .	1.0 gm
Mag. sulphate	MgSO ₄ 7H ₂ O . . .	0.5 gm

Cal. chloride CaCl_2 . . .	trace
Distilled-water . . .	1 litre
Mag. Carbonate . . .	1.0 gm

50 ml portions of this medium were sterilized at 20 lbs pressure for 15 minutes in 500 ml conical flasks plugged with sterile cotton wool. A 10% solution of ammonium sulphate was sterilized separately in a similar manner and the required amount of it added to the flasks containing the sterilized medium under aseptic condition.

One of the flasks was inoculated with 1 gm of fresh garden soil and incubated at 35°C. After eleven days bacterial growth began and was indicated by the appearance of nitrite and disappearance of ammonia; the former being tested by the α -naphthylamine sulphanilic acid test and the latter with Nessler's reagent; the tests being performed every third day in a small portion of the culture solution withdrawn from the flask, till all the ammonium salt was oxidized to nitrite. Then a fresh portion of the sterile $(\text{NH}_4)_2\text{SO}_4$ solution was added. This second portion was oxidized more quickly, since, by now, the nitrite forming bacteria had developed abundantly.

After several additions of ammonium sulphate a vigorous culture was obtained. Now, a drop of the suspension from the bottom of the flask was transferred to another flask containing the same sterilized medium with the help of a sterilized platinum loop. A fairly pure and enriched culture of the specific organism was thus prepared by making four or five such successive transfers and the enriched culture was used for inoculating the experimental flasks.

For preparing an enriched culture of nitrate forming organisms the following medium was employed :—

MEDIUM II. Sod. nitrite (NaNO_2) . . .	1.0 gm
Pot. phosphate (K_2HPO_4) . . .	0.5 gm
Mag. sulphate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) . . .	0.3 gm
Sodium chloride (NaCl) . . .	0.5 gm
Sodium carbonate (NaCO_3) . . .	1.0 gm
Ferrous sulphate (FeSO_4) . . .	0.4 gm
Distilled water . . .	1 litre.

The procedure for preparing an enriched culture was the same as described above, with the difference that in this case periodic tests were made for the appearance of nitrate and disappearance of nitrite. Nitrite was tested with α -naphthylamine-sulphanilic acid test and when it was found to be absent then a portion of the culture was tested with diphenylamine reagent, when appearance of a blue colour indicated the presence of nitrate. At this stage a fresh portion of a sterilized 10% Sod. nitrite solution was fed into the flask. After several additions of sod. nitrite a vigorous culture of the nitrate forming organisms was obtained. This was further purified by making successive transfers as described earlier. The finally obtained pure culture was used for inoculating the experimental flasks.

For the study of nitrification in bacterial cultures the following procedure was adopted :—

- Solution A*—10% Ammonium sulphate solution sterilized
 „ *B*—Containing other constituents of Medium I described above
Solution A'—10% solution of sodium nitrite, sterilized.
 „ *B'*—Containing other constituents of Medium II described above

50 ml portions of solutions *B* and *B'* were taken in sets of three 500 ml conical flasks which were plugged and sterilized at 20 lbs pressure for 20 minutes. In the first set of three flasks containing Solution *B* different amounts of Solution *A* was added with a sterilized graduated pipette and then inoculated with the enriched culture of the nitrite forming organism. In the second set of three flasks containing Solution *B'*, different amounts of Solution *A'* was added and the flasks inoculated with the enriched culture of nitrate forming organisms. All this was done under aseptic conditions.

Now, all the flasks were incubated at a temperature of 35°C for definite periods after which their contents were analysed for their ammoniacal and nitric nitrogen content by the method described below :—

The ammoniacal nitrogen was estimated colorimetrically by Nessler's reagent. Nitric nitrogen was reduced by Devardas' alloy to ammoniacal nitrogen and then estimated as above.

The results obtained are tabulated below :—

TABLE No. 1

Cultures of nitrite formers using ammonium sulphate as the starting source of Nitrogen

Period of incubation—12 weeks

S. No.	Original nitrogen content (present as Am- monium sulphate) gms	Ammoniacal nitrogen left gms	Nitric nitrogen formed gms	Total nitrogen left gms	Total N lost gms	% loss of nitrogen
1.	0.05151	0.000322	0.02500	0.075322	0.026188	50.8
2.	0.03927	0.000500	0.00310	0.003600	0.025670	65.3
3.	0.03250	0.000250	0.00296	0.003210	0.029290	90.0

TABLE No. 2

Cultures of Nitrate formers using Sodium nitrite as the starting source of nitrogen

Period of incubation—10 weeks

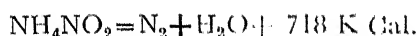
S. No.	Original nitrogen content (present as sodium nitrite) gms	Ammoniacal nitrogen present gms	Nitric nitrogen present gms	Total nitrogen present gms	Total nitrogen lost gms	% loss of nitrogen
1.	0.03151	0.0005	0.0262	0.0267	0.0048	15.2
2.	0.02424	0.0002	0.0168	0.0170	0.00724	30.2

DISCUSSION

The results obtained by the authors clearly indicate that even during the bacterial nitrification of ammonium salt (*i*) there is a marked loss of nitrogen and (*ii*) the loss is greater during the first stage of nitrification, *i.e.*, during the oxidation of nitrite to nitrate. Such losses have been reported by other workers as well.

Beesley⁷ in his experiments had observed that the sum of ammonia and nitrite first falls considerably below the amount of ammonia originally present and then rises to about 90% of the original quantity. Thus, even in his experiments only 90% of the original nitrogen could be accounted for indicating a definite loss of some nitrogen. Pant⁸ also obtained similar results.

The loss of nitrogen during this process has been explained by us on the assumption that during nitrification both ammonium and nitrite ions are present simultaneously. During their co-existence these ions combine to give the unstable compound ammonium nitrite which readily decomposes into nitrogen gas and water. the gaseous nitrogen escapes from the field of reaction, causing the loss of nitrogen thus :—

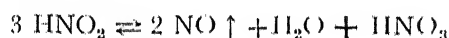


The mechanism of the loss also explains why the loss is greater during the first stage of nitrification *i.e.*, nitrite formation than during the second stage *i.e.*, nitrite oxidation. The assumption, that nitrite and ammonium ions co-exist is supported by the experimental observations of several workers.

Martin⁹ and associates found that between $\frac{1}{4}$ to $\frac{1}{2}$ of the added nitrogen appears as nitrite, before nitrate formation started in their experiments with Arizona desert soils with pH about 7.7 on adding ammonia or urea.

It has been observed by several workers like Dhar and Rao¹⁰, Clorbet,¹¹ Singh and Nair¹² that photo-chemical oxidation of ammonia in solution yields nitrite.

Thus, there is strong evidence to show that nitrate formation in soils takes place through the nitrite stage and hence the mechanism supposed by us to be responsible for the observed loss of nitrogen seems quite probable in case of soils having a pH greater than 7. Some nitrogen may be lost as ammonia gas but under ordinary conditions on adding nitrogenous manures, the pH goes to the acid side and the loss may be partially due to the decomposition of nitrous acid according to the equation.



From all this it will be clear that the process of bacterial nitrification is associated with loss of nitrogen like the photo-nitrification or the chemical conversion of ammonia to nitrate.

SUMMARY

Contrary to the generally accepted idea that pactical conversion of ammonia to nitrate is quantitative though no chemical process oxidizes in such complete manner, it has been observed that an appreciable amount of nitrogen is lost in the nitrification of ammonium sulphate through bacterial agency just like photo-nitrification or the chemical conversion of ammonia to nitrate.

This loss has been explained from the viewpoint that during the process of nitrification, the unstable compound ammonium nitrite is produced as an intermediate product which decomposes into water and nitrogen. The loss may also be partially due to the decomposition of nitrous acid, especially when the pH is less than 7.0.

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STUDIES ON INOCULATION OF SOIL WITH AZOTOBACTER

By

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Inoculation of soil with cultures of certain bacteria was first attempted in 1900 by Caron who observed that the process generally increased crop yields. Since the discovery in 1901 of the aerobic nitrogen fixing organisms of the genus *Azotobacter*, studies on inoculation of soil with *Azotobacter* and increase in nitrogen content of soil thereby were made by several workers (Emerson, 1918 ; Makrinoff, 1924 ; Brown and Hart, 1925 ; Gainey, 1925).

Thompson, (1932) obtained high fixation of atmospheric nitrogen in a soil having a very low nitrogen content and a low *Azotobacter* population by inoculating it with pure culture of *Azotobacter chroococcum* and observed that addition of straw alone increased the total nitrogen content of the soil. William, Martin and Brown, (1937) obtained high fixation of nitrogen in soil under a crop of timothy by inoculation of the soil with *Azotobacter*. Greaves and Jones, (1942) obtained large increases in the nitrogen content of Utah soil where *Azotobacter* was practically absent, by inoculating the soil with *Azotobacter*.

It came to be known, however, that *Azotobacter* required large quantities of organic materials to provide energy for the fixation of nitrogen. Organic matter like root residues of crops were mostly cellulosic and as such they were rather very poor energy materials unless converted by other organisms to simple sugars which could be utilised more efficiently by *Azotobacter*.

McBeth, (1911) observed large fixations of nitrogen by *Azotobacter* in associations with cellulose decomposing organisms. Krishna, (1928) noted that straw was very efficiently utilised by *Azotobacter* when decomposed by cellulose decomposing organisms. Stimulation of the activity of *Azotobacter* in presence of cellulose decomposing organisms was observed by Sanborn and Hamilton, (1929).

Jensen, (1940) observed that nitrogen fixation in soil by *Azotobacter* occurred only in association with cornebacteria and of the cellulose decomposing organisms. Filter paper, grass and straw were utilised by *Azotobacter* with the same efficiency. Shtutser, (1945) stated that *Azotobacter* fixed nitrogen at the expense of the products of cellulose decomposition and itself created favourable conditions for the nutrition for the cellulose decomposing organisms.

During the present investigation, cultures of *Azotobacter* with high nitrogen fixing capacity grown on soil media were mixed alone and in combination with cellulose decomposing organisms isolated from Delhi soil with Delhi soil moistened with one-third its saturation capacity in different proportions and incubated. The

soil mixed with different organic materials like wheat straw (poor in nitrogen), berseem hay (rich in nitrogen) farmyard manure (average nitrogen content) and mannite (no nitrogen) also received treatments with bacterial cultures and incubated under similar conditions. Total and nitrate nitrogen contents as well as the Azotobacter counts were determined in the soil under different treatments at intervals of seven weeks. It was expected that the results would present a clear picture of the survival of the Azotobacter population introduced into the soil by inoculation, utilisation of the energy materials added for fixation of nitrogen and formation of nitrates so that crop growth could not be hindered, during fixation of nitrogen for lack of available nitrogen in the soil.

EXPERIMENTAL PROCEDURE

Preparation of Azotobacter culture in soil medium for inoculation.—Pure strains of Azotobacter were isolated from different soils obtained from different parts of India and their nitrogen fixing capacities in Ashby's solution determined. Fixations during three weeks were only considered. As the strain from Ferozepur soil had the highest nitrogen fixing capacity (5.74 mg/gm of mannite) it was selected for inoculation purposes.

1 kg of Delhi soil which was previously sieved through 1 m.m. sieve was mixed with the following ingredients :—

Mannite 10-gms ; potassium dihydrogen phosphate 0.1 gm ; disodium hydrogen phosphate 0.1 gm ; sodium chloride 0.1 gm ; calcium sulphate 0.1 gm ; ferrous sulphate 0.1 gm ; marmite 0.1 gm ; sodium molybdate 0.002 gm ; distilled water 120 c.c.

The mixture was sterilised in a 2-litre conical flask for two hours at 120°C in an autoclave. Complete sterilisation of the soil was assured by plating out the sterilised soil, when at a dilution of 1:1000 in Thornton's agar, no plate developed any colony. The sterilised soil was thoroughly and aseptically mixed with 10 c.c. of a forty eight hours' old culture of the organisms from Ferozepur in Ashby's mannite solution and incubated at 30°C for four weeks. Determinations of the nitrogen content of the soil in the beginning (0.0336 %) and after four weeks' incubation (0.0420 %) showed an increase of about 84 mg of nitrogen per kg of the soil. Platings of the soil culture also showed a large Azotobacter population which numbered 238 millions per gm of the soil (203, 246, 302, 216, 222 at a dilution of 1:1000,000).

Preparation of the culture of the cellulose decomposing organisms.—100 c.c. of Lohnis' ammonium sulphate cellulose solution in which strips of filter paper were added, were inoculated with one gram of Delhi soil. The solution was incubated for several days till the filter paper got dissolved. After several transfers when contamination of the cellulose decomposing organisms from others were expected to be eliminated to a large extent, 1000 c.c. of sterile Lohnis' solution with pieces of filter papers were inoculated with the culture from the last transfer. When the growth of the organisms was most vigorous and the filter papers got dissolved, the liquid was used for soil inoculation.

Soil, wheat straw, farmyard manure and berseem hay.—The soil was collected up to a depth of 0.6" from a plot of poor fertility. It was air dried and sieved through a 1 m.m sieve and used during the experiments. The wheat

straw, farmyard manure and the berseem hay were dried and powdered uniformly. The composition of the soil and of the organic materials is given in the Appendix 1.

Nitrogen fixation and nitrification.—Soil was mixed thoroughly with the Azotobacter soil culture in required proportions and with the other ingredients in a porcelain basin previously sterilised by drying with alcohol with a pre-heated iron spatula and sterile water equivalent to one-third the saturation capacity of the soil was added. In case of inoculation with culture of cellulose decomposing organisms allowance was made of the volume of liquid added while moistening the mixture with water. The mixtures were then put in wide mouthed bottles and incubated at 30°C. Losses of moisture were made up from time to time with additions of fresh sterile water. Determinations of total and nitrate nitrogen as also of Azotobacter counts were made at intervals of seven weeks. The observations were carried out for a total period of fourteen weeks.

The experiments were conducted in duplicate series for each treatment and determination in duplicates for each sample.

RESULTS

Nitrogen contents of Delhi soil with and without treatment of different organic materials and receiving treatments with Azotobacter culture singly and in combination with cellulose decomposing organisms at different periods are given in Table I.

TABLE No. I

Average nitrogen contents of Delhi soil under different treatments and at different periods
(mg%)

Treatment	At start	After seven weeks	After fourteen weeks	Gain or loss
Delhi soil without any addition of organic material				
Uninoculated soil	33.6	33.6	33.6	...
Soil + cell. org.—	35.0	35.0	35.0	...
Soil + 5 % Azo.—	35.0	35.0	35.0	...
Soil + 5 % Azo. + cell. org.—	35.0	35.0	36.4	+1.4
Soil + 10 % Azo.—	36.4	36.4	36.4	...
Soil + 10 % Azo. + cell. org.—	35.0	35.0	37.8	+2.8
Soil + 20 % Azo.—	36.4	36.4	37.8	+1.4
Soil + 20 % Azo. + cell. org.—	33.6	34.3	35.0	+1.4

Treatment	At start	After seven weeks	After four- teen weeks	Gain or loss
Soil treated with 1 % Wheat straw				
Uninoculated soil—	37·8	37·8	37·8	...
Soil+cell. org.—	37·8	39·2	39·2	+1·4
Soil+5 % Azo.—	37·8	39·2	39·2	+1·4
Soil+5 % Azo.+ cell. org.—	37·8	37·8	39·2	+1·4
Soil+10 % Azo.—	37·8	39·2	40·6	+2·8
Soil+10 % Azo.+ cell. org.—	36·4	40·6	42·0	+5·6
Soil+20 % Azo.—	37·8	39·2	39·2	+1·4
Soil+20 % Azo.+ cell. org.—	37·8	38·5	42·0	+4·2
Soil treated with 1 % Berseem hay				
Uninoculated soil—	70·0	70·0	70·0	...
Soil+cell. org.—	70·0	70·0	70·0	...
Soil+5 % Azo.—	68·6	68·6	68·6	...
Soil+5 % Azo.+ cell. org.—	70·0	70·0	70·0	...
Soil+10 % Azo.—	71·4	71·4	71·4	...
Soil+10 % Azo.+ cell. org.—	71·4	71·4	71·4	...
Soil+20 % Azo.—	70·0	70·0	70·0	...
Soil+20 % Azo.+ cell. org.—	69·3	69·3	69·3	...
Soil treated with 1 % Farmyard manure				
Uninoculated soil—	49·0	49·7	50·0	+1·4
Soil+cell. org.—	49·0	49·7	51·8	+2·8
Soil+5 % Azo.—	44·1	46·9	47·6	+3·5
Soil+5 % Azo.+cell. org.—	44·8	45·5	50·4	+5·6
Soil+10 % Azo.—	47·6	49·0	50·4	+2·8
Soil+10 % Azo.+ cell. org.—	46·9	49·7	49·7	+2·8
Soil+20 % Azo.—	44·8	49·7	49·7	+4·9
Soil+20 % Azo.+cell. org.—	44·8	45·5	47·6	+2·8
Soil treated with 1 % Mannite				
Uninoculated soil—	33·6	37·1	37·8	+4·2
Soil+cell. org.—	33·6	39·9	39·9	+6·3
Soil+5 % Azo.—	35·0	41·3	41·3	+6·3
Soil+5 % Azo.+cell. org.—	35·0	38·5	40·6	+5·6
Soil+10 % Azo.—	36·4	39·9	40·6	+4·2
Soil+10 % Azo.+cell. org.—	36·4	38·5	39·2	+2·8
Soil+20 % Azo.—	36·4	39·9	40·6	+4·2
Soil+20 % Azo.+ cell. org —	36·4	39·2	39·2	+2·8

From the data in table I, it could be observed that except for treatment with berseem hay, there was fixation of nitrogen in many cases and very often maximum fixation of nitrogen in the treatments of soil with common organic matter was caused by Azotobacter in association with cellulose splitting organisms.

Results of determination of Azotobacter counts in Delhi soil receiving different treatments of organic materials and bacterial inoculations are given in table II.

TABLE No. II

Average Azotobacter counts in Delhi soil receiving treatments of different organic matter and bacterial inoculations at different periods (millions per gram of air dry soil)

Treatment	At start calculated	observed*	After seven weeks	After four- teen weeks
Delhi soil without any treatment				
Uninoculated soil—	3.30	15.80	0.36	0.50
Soil+cell. org.—	3.30	15.80	0.32	0.50
Soil+5 % Azo.—	14.48	22.00	0.40	1.08
Soil+5 % Azo.+cell. org.—	14.48	22.00	0.68	1.60
Soil+10 % Azo.—	24.64	23.00	0.74	1.20
Soil+10 % Azo.+cell. org.—	24.64	23.00	0.84	1.48
Soil+20 % Azo.—	42.42	36.60	1.00	2.56
Soil+20 % Azo.+cell. org.—	42.42	36.60	1.34	1.56
Soil with 1 % Wheat straw				
Uninoculated soil—	3.30	15.80	1.42	1.34
Soil+cell. org.—	3.30	15.80	1.10	0.98
Soil+5 % Azo.—	14.48	22.00	1.24	1.46
Soil+5 % Azo.+cell. org.—	14.48	22.00	1.68	2.20
Soil+10 % Azo.—	24.64	23.00	1.94	3.36
Soil+10 % Azo.+cell. org.—	24.64	23.00	1.64	2.42
Soil+20 % Azo.—	42.42	36.60	2.02	3.58
Soil+20 % Azo.+cell. org.—	42.42	36.60	2.54	3.90
Soil with 1 % Berseem hay				
Uninoculated soil—	3.30	15.80	2.98	3.30
Soil+cell. org.—	3.30	15.80	1.58	1.98
Soil+5 % Azo.—	14.48	22.00	2.94	3.26
Soil+5 % Azo.+cell. org.—	14.48	22.00	2.88	2.74
Soil+10 % Azo.—	24.64	23.00	3.16	4.94
Soil+10 % Azo.+cell. org.—	24.64	23.00	4.46	4.34
Soil+20 % Azo.—	42.42	36.60	6.24	5.88
Soil+20 % Azo.+cell. org.—	42.42	36.60	4.66	6.60

*The platings were done in moist soil after six hours.

Treatment	At start calculated	observed*	After seven weeks	After four- teen weeks
Soil with 1 % Farmyard manure				
Uninoculated soil—	3.30	15.80	0.74	0.56
Soil+cell. org.—	3.30	15.80	0.82	0.40
Soil+5 % Azo.—	14.48	22.00	0.60	1.14
Soil+5 % Azo.+cell. org.—	14.48	22.00	0.82	1.44
Soil+10 % Azo.—	24.64	23.00	1.14	2.34
Soil+10 % Azo.+cell. org.—	24.64	23.00	2.16	1.74
Soil+20 % Azo.—	42.42	36.60	1.68	4.34
Soil+20 % Azo.+cell. org.—	42.44	36.60	1.56	4.82

Soil with 1 % mannite				
Uninoculated soil—	3.30	15.80	3.18	3.00
Soil+cell. org.—	3.30	15.80	2.62	2.98
Soil+5 % Azo.—	14.48	22.00	2.72	3.88
Soil+5 % Azo.+cell. org.—	14.48	22.00	2.88	3.18
Soil+10 % Azo.—	24.64	23.00	3.62	4.66
Soil+10 % Azo.+cell. org.—	24.64	23.00	2.08	6.36
Soil+20 % Azo.—	42.42	36.60	4.44	4.08
Soil+20 % Azo.+cell. org.—	42.42	36.60	5.00	4.84

From the data in table II it would be clear, that higher counts of Azotobacter were generally obtained with higher applications of Azotobacter culture in all the treatments. It could also be observed that the chances of survival of such a large number of Azotobacter introduced into the soil through inoculation were very few indeed under normal agricultural conditions.

Nitrate nitrogen contents of Delhi soil under different treatments of organic materials and inoculated with cultures of Azotobacter and cellulose splitting organisms, during the periods under observations are given in table III.

TABLE No. III

Average nitrate nitrogen contents of Delhi soil under different treatments
Expressed as mg % on air dry soil which originally contained
0.45 mg % nitrate nitrogen

Treatment	After seven weeks	After fourteen weeks
Delhi soil without any treatment		
Uninoculated soil—	1.50	2.10
Soil+cell. org.—	1.50	2.40
Soil+5 % Azo.—	1.50	2.10
Soil+5 % Azo.+cell. org.—	1.50	2.70
Soil+10 % Azo.—	2.10	2.70
Soil+10 % Azo.+cell. org.—	2.10	3.00
Soil+20 % Azo.—	1.80	2.40
Soil+20 % Azo.+cell. org.—	1.50	3.00

*The platings were done in moist soil after six hours.

Treatment	After seven weeks	After fourteen weeks
Soil with 1 % Wheat straw		
Uninoculated soil—	0.30	0.60
Soil+cell. org.—	0.45	0.45
Soil+5 % Azo.—	0.45	0.45
Soil+5 % Azo.+cell. org.—	0.45	0.45
Soil+10 % Azo.—	0.45	0.45
Soil+10 % Azo.+cell. org.—	0.45	0.45
Soil+20 % Azo.—	0.45	0.45
Soil+20 % Azo.+cell. org.—	0.60	0.60
Soil with 1 % Berseem hay		
Uninoculated soil—	8.40	11.40
Soil+cell. org.—	9.60	11.40
Soil+5 % Azo.—	8.40	12.00
Soil+5 % Azo.+cell. org.—	8.40	13.00
Soil+10 % Azo.—	8.40	9.60
Soil+10 % Azo.+cell. org.—	10.80	11.40
Soil+20 % Azo.—	8.40	12.00
Soil+20 % Azo.+cell. org.—	7.20	12.00
Soil with 1 % Farmyard manure		
Uninoculated soil—	3.00	3.30
Soil+cell. org.—	3.90	5.40
Soil+5 % Azo.—	2.70	3.90
Soil+5 % Azo.+cell. org.—	2.70	4.20
Soil+10 % Azo.—	3.00	4.20
Soil+10 % Azo.+cell. org.—	3.00	4.80
Soil+20 % Azo.—	4.20	4.20
Soil+20 % Azo.+cell. org.—	2.70	4.20
Soil with 1 % Mannite		
Uninoculated soil—	0.45	1.05
Soil+cell. org.—	0.45	1.35
Soil+5 % Azo.—	0.60	0.60
Soil+5 % Azo.+cell. org.—	0.60	1.50
Soil+10 % Azo.—	0.60	0.75
Soil+10 % Azo.+cell. org.—	0.45	0.45
Soil+20 % Azo.—	0.45	1.20
Soil+20 % Azo.+cell. org.—	0.45	1.05

It could be observed from the data in table III that appreciable nitrification had taken place only in cases of treatment with berseem hay and farmyard manure. Inoculation of the soil with cultures of Azotobacter or cellulose decomposing organisms apparently had no effect on the rate of nitrification.

DISCUSSION OF RESULTS

It is clear from the data in table I that no remarkable fixation of nitrogen takes place by inoculating a soil under natural conditions with a soil culture of Azotobacter in any proportion singly or in combination with cellulose splitting

organisms when no organic matter is added to the soil. When wheat straw is added to the soil, appreciable fixation of nitrogen takes place only when Azotobacter culture is added to soil (10 % along with the cellulose splitting organisms. The proportion of Azotobacter culture required is much lower (5 %) when farmyard manure is added to soil to obtain a fair amount of fixation of nitrogen. With treatment of a soil with mannite, large fixations of nitrogen are caused by addition of soil culture of Azotobacter amounting to 5 % on the soil along with the cellulose decomposing organisms. When berseem hay is added to soil, there is no fixation of nitrogen even when the soil is inoculated with large proportions of Azotobacter culture. The higher nitrogen content of the hay may be sufficing for the nitrogen requirements of Azotobacter with the result that no fixation takes place.

In spite of large Azotobacter numbers introduced into the soil by incorporation of the soil culture with soil, the Azotobacter counts fell considerably with progress of time (table II). When organic materials are added to soil, the counts are generally maintained at a higher level than in the case of the soil without treatment. Largest counts are obtained in the soil treated with mannite. Soil treated with berseem hay maintains fairly large Azotobacter counts in spite of lack of fixation of nitrogen by them. It seems possible that diminution of Azotobacter number following inoculation with the culture in soil, is due to competition with other organisms existing in the soil. Whatever may be the case it seems certain that chances of survival of a large number of Azotobacter introduced into the soil by inoculation with soil culture, are very limited.

Highest nitrification has been noticed in the case of soil treated with berseem hay irrespective of inoculation with Azotobacter (table III). It may be due to its larger nitrogen content. Soil receiving farmyard manure shows fair amounts of nitrate nitrogen. Soil treated with wheat straw has the lowest nitrate nitrogen content at different periods.

Crop growth requires large amounts of nitrate nitrogen and nitrogen fixation alone, without nitrate formation in soil is not considered as essential need in crop production and soil management. It has been noticed that, in the case of farmyard manure, fair amounts of nitrate nitrogen are present in the soil while showing nitrogen fixation when inoculated with Azotobacter culture. It may, therefore be concluded at this stage of the investigations, that soil treated with farmyard manure alone is benefitted by application of soil culture of Azotobacter to the extent of 5 % in association with cellulose splitting organisms.

SUMMARY AND CONCLUSIONS

A culture of Azotobacter chroococcum of high nitrogen fixing capacity was prepared in soil medium and it was added in different proportions singly and in association with cellulose decomposing organisms to Delhi soil with and without treatments of wheat straw, berseem hay, farmyard manure and mannite. Total nitrogen contents and Azotobacter counts of the soil under different treatments were determined at intervals of seven weeks. The object of the experiment was to see if by soil inoculation, Azotobacter population of and nitrogen fixation in a soil could be increased.

It was observed that presence of organic materials in soil was essential for higher nitrogen fixation. Soil culture of Azotobacter along with cellulose decomposing organisms when added to soil to the extent of 10 % gave maximum fixation

of nitrogen in the case of untreated soil and soil treated with wheat straw. There was no fixation of nitrogen in the case of berseem hay treatment. The *Azotobacter* culture (5 %) with cellulose decomposing organisms gave maximum fixation of nitrogen in the case of soil treated with farmyard manure.

Large *Azotobacter* population introduced into the soil by inoculation did not survive under natural conditions and the counts fell considerably with progress of time. The soils receiving organic materials however, maintained, though lower than the introduced, larger counts of *Azotobacter* than the untreated soil.

Highest nitrification was observed in the cases of soil treated with berseem hay followed by the soil treated with farmyard manure. No appreciable nitrification was observed in the case of other treatments.

Inoculation of the soil treated with farmyard manure with a 5 % soil culture of *Azotobacter* along with cellulose decomposing organisms was considered a very desirable treatment from the point of view of formation of nitrates which are required by plants during growth and also of fixation of nitrogen for the improvement of nitrogen status of the soil.

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APPENDIX I

I. Nitrogen content and Azotobacter count in Delhi soil

Nitrogen contents expressed on moisture free and *Azotobacter* count on air dry basis

Total nitrogen (%)	0.0336
Nitrate nitrogen (%)	0.00045
Azotobacter count (millions per gm)	3.3

II. Nitrogen content of the Organic materials

Expressed as % on moisture free basis

Wheat straw	0.40
Farmyard manure	1.66
Berseem hay	3.40

INFECTION OF LEGUMINOUS PLANTS WITH NITROGEN FIXING ORGANISMS FROM WINDBORNE SOIL.

By

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Organisms in the leaves of rahar (Cajanus cajan). During studies on nitrogen fixation by cultivated legumes it was observed that juice of rahar leaves which were washed with sterile water before extraction, increased in nitrogen content on incubation for a period ranging from two to three weeks. When sterile extracts of washed rahar leaves were inoculated with a drop of the fermenting liquid similar fixations took place. Repeated serial transfers of loopfuls of the liquid to fresh sterile Ashby's mannite solutions caused fixations of nitrogen in each case and it was traced to the presence of some nitrogen fixing organisms in the original extract of rahar leaves. As the extractions were made under aseptic conditions, the organisms must have been present in the leaves themselves. Sterilisation of the surface of the leaves, by steeping in mercuric chloride solution before washing with water for preparation of the extract did not prevent development of the organisms. It was, therefore, considered that the organisms might be present not only on the surface of the leaves but also inside the leaves. On examination, the diluted juice revealed the presence of organisms of almost similar oval rod shape under the microscope. These were not noticed in extracts of leaves of the plant grown under pot culture conditions. The organisms, therefore developed only under field conditions and most possible cause of the existence of the organisms must have been the windborne dust falling on the leaves. While on the leaves some of the organisms could eventually make an entry into the leaf tissues. The functions of the organisms in the nitrogen nutrition of the plant are not known and are under study. The morphological, cultural and biochemical characteristics of the organisms together with their nitrogen fixing capacity are given in the following pages.

Isolation.—The organisms were readily isolated in mannite agar from a loopful of extract of rahar leaves after sterilisation by steeping in mercuric chloride solution and repeated washing with sterile water or with repeated washing with sterile water alone. The colonies in dilution plates were oval, opaque and raised. The studies on the organism were made from several isolates each from a separate extract. Each isolate was replated and single colony cultures obtained prior to each series of tests.

Morphology.—The organism was a short rod, 2.3μ — 3.2μ in dimensions, highly motile, gram negative, non-capsulated and formed no spores. It stained readily with carbol fuchsin, gentian violet and methylene-blue.

Cultural characteristics.—Cultures on nutrient agar were opaque, slimy and coloured light brown after several days. In Ashby's mannite solution surface growth was abundant with formation of pellicle. No growth in nutrient broth or in solutions of sugars in presence of peptone was exhibited. The organism was aerobic. Growth on potato was glossy but barely visible becoming brownish after a few days. Optimum temperature for growth was near about 30°C.

Biochemical characteristics.—The organism decomposed sugars in solution with formation of CO₂ but exhibited no action on sugars in presence of peptone. Milk or litmus milk remained unchanged within ten days. Nitrates were not reduced and starch not hydrolysed. Indole, hydrogen sulphide or ammonia were not produced. The organism did not liquefy gelatin nor showed any surface growth.

Nitrogen fixation.—Nitrogen fixing capacity of the organism in different media is given below (the figures quoted are averages of three determinations and after deduction of blanks) :—

Media	mg N fixed during a period of fourteen days
Rahar leaf extract (1:5) 100 c.c.	5.4
Ashby's mannite solution (100 c.c.) containing 1 c.c. of leaf extract	4.7
Ashby's mannite solution 100 c.c.	4.5

Identity.—From the characteristics of the organism it was found to resemble *Azotobacter chroococcum* very strongly (Bergey, 1948).

Organisms on the stem of the shola pith plant (Aeschynomene aspera).—During studies on the wild leguminous plants, it had been observed that the common water legume, the shola pith plant which grew wild in paddy fields and low lying areas had no nodules at the roots but some tubercular raised outgrowths on the stem immediately above the submerged portions. The outgrowths extended from the bottom to some height along the stem. When these outgrowths were detached from the stem and crushed with water and the suspensions examined under the microscope, they were found to contain numerous organisms of similar shape. The functions of these organisms was suspected to be the same as that of root nodule bacteria in common leguminous plants. It was observed that if these plants were grown from sterilised seeds in sand culture, the tubercular outgrowths developed very rarely. At the same time, they had to be supplied with combined nitrogen for normal development.

Isolation.—The organism was readily isolated from soil extract mannite agar (Joshi, 1920 ; Fred and McCoy, 1932) following Bushnell and Sarles' method (Bushnell and Sarles, 1937). The colonies in dilution plates were colourless, transparent and raised. The studies on the organism were made from several isolates each from a separate outgrowth. Each isolate was replated and single colony cultures obtained prior to each series of tests.

Morphology.—The organism was found to be a short rod with rounded ends occurring single or in chains of two and three. It was motile, gram negative, capsulated and a non-spore former. The average dimensions of the organism from a week old culture were found to be 1.32 μ —0.72 μ . It stained readily with carbol fuchsin, gentian violet and methylene blue.

Cultural characteristics.—The organism showed good growth in nutrient broth without forming a pellicle. Growth on soil extract mannite agar was transparent, raised and glistening like dew drops. It exhibited poor growth in Ashby's mannite agar but profuse growth on Ashby's mannite agar containing 0.05% asparagin or soil extract. Growth on potato cylinders had been copious moist, slimy and of a cream colour. The organism was aerobic. The optimum temperature for growth had been observed to be between 32°C–36°C.

Biochemical reactions.—The organism decomposed sugars like glucose, dextrose, sucrose, lactose, maltose, arabinose, mannose, raffinose and galactose with production of gas but very slight acidity. Gas was also produced in glycerine, mannite and salicin. Milk and litmus milk was curdled within two to three days with production of gas and reduction of litmus. It produced profuse turbidity in nutrient broth turning it slightly acid in the beginning and then alkaline after ten days. Starch was not hydrolysed nor hydrogen sulphide formed. Nitrates were reduced to nitrites with great rapidity. The organism did not liquefy gelatine but produced slight surface growth.

Nitrogen fixation.—The organism, in the free state, had only very feeble capacity for fixation of atmospheric nitrogen. Average amounts of nitrogen fixed by the organism in mg per gram of the sugars during a period of three weeks in presence of CaCO_3 are given below: No fixation of nitrogen was observed in the absence of CaCO_3 (The figures quoted are averages of three determinations and after deduction of blanks in each case).

Substance	mg N fixed/gm of substance
Mannite	1.0
Glucose	0.8
Sucrose	0.6
Lactose	...

Identity.—Nodulation was not observed, on inoculation with the organism, on lucerne (*Medicago sativa*), berseem (*Trifolium alexandrinum*), pea (*Pisum sativum*), urid (*Phaseolus radiatus*), white lupin (*Lupinus albus*) and soya bean (*Glycine max*). It appeared from the general characteristics of the organism, however, that the organism may belong to the family Rhizobiaceae (Bergey, *loc. cit.*). Further tests for the identification of the organism are in progress.

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PURPLE BACTERIA IN PADDY SOILS

By

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In paddy fields, the crop yield maintains comparatively higher level than upland fields without any decline in the fertility of the soil year after year when no fertilizer or manure is supplied.

To understand this phenomenon, we must expect that the soils obtain supplies of plant nutrients from somewhere by nature, otherwise the crop would cease to grow and the maintenance of the soil fertility could not be brought about. Especially, regarding nitrogen supply, many investigators have centered their scientific interests and the most possible nitrogen supplier have been considered to be blue green algae having the ability of the atmospheric nitrogen fixation under water-logged conditions and in our laboratory the algae in paddy fields have been also investigating and it was confirmed that blue green algae contributed much to fertilize these soils.

Of late E. S. Lindstrom^{3,4} and his co-workers reported that many species belonging to Athiorhodaceae and some species of Thiorhodaceae had the ability of the atmospheric nitrogen fixation. As they can fix nitrogen autotrophically under anaerobic conditions, it is considered to be possible to play a role as the nitrogen supplier in paddy fields. For this reason, we have been studying whether they have the practical value or not and report the occurrence of purple bacteria in paddy soils in this paper.

Soil sampled from one of our experimental paddy field, air-dried soil sampled last year from the same place, and soil from potato field under dry cultivated conditions in Kyoto University were used as inocula.

For this experiment, solution of the following composition was used as culture medium.^{1,2,3}

dl-malic acid	2.0 gms	NaHCO ₃	5.0 gms
(NH ₄) ₂ SO ₄	1.0 gm	Yeast extract	10 c.c.
K ₂ HPO ₄	0.5 gm	Peptone water	12 c.c.
MgSO ₄	0.2 gm	dist. water	1000 c.c.
NaCl	2.0 gm	pH was adjusted at 7.0 with H ₃ PO ₄	

30 c.c. of the culture solution was poured into each of 50 c.c. Erlenmeyer flask and pasteurized. After these media were inoculated with 100 mg of soil, they were intercepted from air with 15 c.c. of liquid paraffin and were incubated in a thermostat equipped with fluorescent lamps at 30°C.

After a week, media inoculated with the soil from paddy field began to be turbid and soon turned brownish red. Media inoculated with the dried soil spent three weeks until they turned red. But that inoculated with the potato soil did not show such a significant colour change.

These coloured organisms were transferred to sulphur free sub-culture and incubated to determine their taxonomic positions and physiological properties. Most of them were short rod-shaped and slightly curved (0.5μ by $1\sim 10\mu$). Branch ed cell was also observed among them. They were seen not to be pigmented under a microscope, but appeared dark red in masses. Though it cannot be said decisively as yet, we have tentatively determined them to be *Rhodospseudomonas pulstris* from the close resemblance in the morphological characteristics.¹

Jensen⁵ said as to the agricultural significance of the biological nitrogen fixation as follows :—

From the practical point of view it would appear that comparatively little can be done to increase the yield of the non-symbiotic heterotrophic process. Firstly, the gains can only be expected to reach significant proportions in neutral or alkaline soils of adequate phosphate content, and liming of the soil to such a reaction is not practicable everywhere. Even more decisive is the provision of organic matter which, to promote nitrogen fixation, would have to be of a fairly wide C : N ratio, because otherwise the resulting formation of ammonia would immediately put a stop to the nitrogen fixation. But it is well-known that incorporation of large amounts of such materials into the soil is undesirable, inter alia, because it entails nitrogen starvation of the crop due to the locking up of available soil nitrogen.

We are of the same opinion, on which we have been studying the agricultural significance of the nitrogen fixation by the autotrophic organisms such as blue green algæ and purple bacteria. From this point of view, it is of much interest and worth while considering further that purple bacteria were found in paddy soils using only 100 mg of soil samples.

In regard the inoculum, van Niel¹ showed that it is possible to contain large enough numbers to yield positive results when 1~5g rich soil sample is used. Considering that they were easily separated from far smaller quantities of paddy soil compared with ordinary soils, it can readily be imagined that they find their suitable habitat in paddy fields.

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NITRIFICATION IN THE PRESENCE OF ORGANIC MATTER

By

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The process of nitrification is greatly affected by the presence of organic matter. Doryland (1916) concluded that no organic substance is required for nitrification, this process being an autotrophic oxidative phenomenon. Hutchinson (1918) and Russell (1927) observed that the application of a carbohydrate to the soil caused a decrease in the soil nitrates, whereas the work of Blair and Prince (1928) showed that after addition of fresh organic matter to the soil, there is in the beginning a depression in the $\text{NO}_3\text{—N}$ of the soil. This depression, they attribute not to any particular toxic compound or to the organisms added, but to the stimulation of the biological activities with the resulting NO_3 assimilation. Richards and Shrikhande (1935) found that both $\text{NH}_3\text{—N}$ and $\text{NO}_3\text{—N}$ are used by the organisms for their body protein in the decomposition of the plant materials. Anderson (1926) indicated that nitrification can proceed in the presence of celluloses; but unless nitrogen is present in quantities above that required by the bacteria, the nitrates are utilized as rapidly as they are formed.

On the other hand, it is suggested by some workers that supplementing the nitrogenous fertilizers like ammonium sulphate with organic matter is beneficial in conserving their nitrogen which is subjected to a considerable ready loss from the soil owing to the solubility and disappearance in the gaseous form. The purpose of this investigation, therefore, was to make an attempt to bring out in some detail the effect of an easily decomposable organic substance upon the process of nitrification with a view to elucidating the role of addition of organic matter along with the nitrogenous fertilizers.

METHOD OF INVESTIGATION

Soil is a very complex system consisting of innumerable factors and since it becomes difficult to control several factors in any one investigation, it was considered desirable to use an inert medium like sand in place of soil, so that the experiments could be planned to take into account only nitrogen and organic matter changes which were sought to be studied here. Accordingly, 100g of thoroughly washed pure sand were taken in each Erlenmeyer flask of 250 ml capacity. The nutrient culture solution of Winogradsky medium No. 48 was used for the nitrifying organisms except the source of nitrogen which was taken in the form of ammonium sulphate at 4 levels of 10, 20, 30 and 40 mg N per 100g of sand for studying the process of nitrification.

In order to observe the effect of organic matter upon nitrification, mannitol was selected as an easily decomposable organic material and was added in varying amounts in different experiments. Each flask was inoculated with 1 ml of a dilute extract of a well-manured garden soil in distilled water, and the flasks were incubated at 35°C for a period ranging from 30 to 60 days. Each experiment was quadruplicated. At the end of this period the contents of the flasks were analysed for (i) $\text{NH}_3\text{—N}$ by distilling with magnesia, (ii) $\text{NO}_2\text{—N}$ by Griess Illosvay's colorimetric method, (iii) $\text{NO}_3\text{—N}$ by the phenoldisulphonic acid method, (iv) total N by the standard Kjeldahl method, and (v) pH by the glass electrode method (the soil water ratio being 2:5). The values for initial pH were also determined at the start of each experiment.

EXPERIMENTAL RESULTS

TABLE No. 1

Nitrification after 30 days in the presence of 1 g mannitol per flask

Treatment	pH		Mineral N in mg			Total	Total N in mg
	Initial	Final	$\text{NH}_3\text{—N}$	$\text{NO}_2\text{—N}$	$\text{NO}_3\text{—N}$		
10 mg N	8.20	8.25	0.136	Traces	Traces	0.136	9.87
20 „ N	8.15	8.20	0.203	„	„	0.203	19.46
30 „ N	8.20	8.20	0.280	„	„	0.280	29.19
40 „ N	8.20	8.15	0.308	„	„	0.308	39.03

The data in table 1 reveal that in the presence of 1 g mannitol nitrification was extremely poor, being in fact more or less at a standstill. At the end of 30 days only traces of $\text{NO}_2\text{—N}$ and $\text{NO}_3\text{—N}$ were formed, while the amount of $\text{NH}_3\text{—N}$ was very meagre. In general, even less than 0.3 mg $\text{NH}_3\text{—N}$ was obtained out of the total N added, indicating thereby that almost all the mineral N was converted into the organic form by the micro-organisms. The initial and final pH were almost the same.

TABLE No. 2

Nitrification after 60 days in the presence of 1 g mannitol per flask

Treatment	pH		Mineral N in mg			Total	Total N in mg
	Initial	Final	$\text{NH}_3\text{—N}$	$\text{NO}_2\text{—N}$	$\text{NO}_3\text{—N}$		
10 mg N	8.10	7.95	1.246	0.018	Traces	1.264	9.73
20 „ N	8.10	7.90	2.016	0.019	„	2.035	19.04
30 „ N	8.15	8.20	2.408	0.019	„	2.427	28.56
40 „ N	8.15	8.15	3.052	0.018	„	3.070	38.71

From table 2 it is evident that when the period of incubation was increased to 60 days keeping 1 g mannitol constant, some nitrate was formed. In addition to $\text{NH}_3\text{—N}$ some $\text{NO}_2\text{—N}$ was also formed. There was however, a greater production of $\text{NH}_3\text{—N}$. This was apparently due to the mineralization of N in the micro-organic tissues elaborated in the early period of decomposition. The amount of $\text{NH}_3\text{—N}$ with 40 mg level of N was 3.052 mg as against only 0.308 mg obtained in the first experiment. However, $\text{NO}_3\text{—N}$ was formed only in traces which showed still a slow progress in nitrification. The initial and final pH did not show much variation.

TABLE No. 3

Nitrification after 60 days in the presence of $\frac{1}{2}$ g mannitol per flask

Treatment	pH		Mineral N in mg.				Total N in mg
	Initial	Final	NH ₃ —N	NO ₂ —N	NO ₃ —N	Total	
10 mg N	8.10	8.00	0.854	0.028	0.435	1.317	9.52
20 „ N	8.15	7.80	1.554	0.068	0.871	2.493	19.46
30 „ N	8.20	7.80	2.296	0.143	1.388	3.827	29.40
40 „ N	8.15	7.90	2.758	0.113	0.308	3.179	39.55

A careful perusal of the data in table 3 indicates that all the three forms of nitrogen *i.e.*, NH₃—N, NO₂—N and NO₃—N were formed when the amount of mannitol was reduced to $\frac{1}{2}$ g per flask and the period of incubation was maintained at 60 days. The amount of NH₃—N in this case also was appreciable. There was a consistent increase in the amount of NO₃—N with the increasing level of N only up to 30 mg N and then there was a gradual decrease in its amount as soon as the level of N was increased to 40 mg with 10 mg N the amount of NO₃—N was 0.435 mg and it increased to as high as 1.388 mg with 30 mg level of N, but only 0.308 mg was obtained with 40 mg level of N. Similar was the case with total mineral N. Like the previous experiments there was no marked difference between the initial and final reaction.

TABLE No. 4

Nitrification after 60 days without mannitol

Treatment	pH		Mineral N in mg				Total N in mg
	Initial	Final	NH ₃ —N	NO ₂ —N	NO ₃ —N	Total	
10 mg N	7.85	7.70	0.812	0.054	1.846	2.712	9.87
20 „ N	7.80	7.60	0.938	0.089	3.541	4.568	19.81
30 „ N	7.85	7.50	1.148	0.092	5.500	6.740	29.82
40 „ N	7.90	7.60	1.666	0.085	3.038	4.789	39.90

A comparative study of the data in Table No. 4 and the previous ones shows that in the absence of mannitol the process of nitrification had increased considerably. In this case the amount of NO₃—N formed was sufficiently high. It had risen as high as 5.5 mg as compared to almost less than 1.0 mg in other cases. Likewise, a distinct increase in total mineral N was also noticed. On the contrary the amount of NH₃—N showed a significant decrease, indicating that the nitrifying organisms converted it into NO₃—N allowing little for accumulation. In this case also 30 mg level of N exhibited the maximum amount of nitrate formation. The effect of varying concentrations of mannitol upon nitrification has been graphically represented in figure 1.

DISCUSSION

Mannitol was added as an easily decomposable organic material and it was found that the process of nitrification was adversely affected by its presence in the medium. With a greater quantity of mannitol (1 g per flask) and shorter period of incubation (30 days) most of the ammoniacal N was converted into the organic form. This may be attributed to the fact that the added mannitol supplied a ready source of energy which stimulated the multiplication of the organisms over

the period investigated. On the other hand, with a longer period of incubation (60 days) greater liberation of mineral nitrogen in the form of $\text{NH}_3\text{—N}$ was obtained. Because, during this period the synthesized microbial tissue began to decompose, thus liberating $\text{NH}_3\text{—N}$ Hutchings and Martin (1934) also arrived at a similar conclusion.

A reduction in the amount of mannitol to $\frac{1}{2}$ g per flask brought about a further enhancement in nitrification. This was owing to a decrease in the amount of the heterotrophic organisms and a consequent retardation in the development of the heterotrophic organisms. Conditions now became favourable for nitrification and nitrates accumulated in the medium.

Still greater nitrification was noted when no mannitol at all was added to the medium. Under this condition there was no chance for the development of the heterotrophic organisms and the nitrifying organisms, being autotrophic in nature, multiplied freely promoting accumulation of $\text{NO}_3\text{—N}$. It may be inferred from this fact that no organic matter is required for nitrification. Waksman (1927) pointed out a competition between the organisms and the higher plants for the available nitrogen. This explains that when the nitrogenous fertilizers are added to the soil together with large quantities of organic manures, the available energy introduced into the soil allows a rapid growth of the organisms with the result that the available N is used up by them to the detriment of the plant growth. The presence of organic matter in the soil may, however, be helpful in conserving its nitrogen and in liberating it slowly for the need of the crop as suggested by some workers.

As regards the individual levels of nitrogen the data proved that the highest amount of $\text{NO}_3\text{—N}$ was obtained at 30 mg level of N and this figure dropped when the level was raised to 40 mg per flask. From this low return in $\text{NO}_3\text{—N}$ over 30 mg N it appears that the level of N above 30 mg exercises some toxic effect upon the nitrifying organisms.

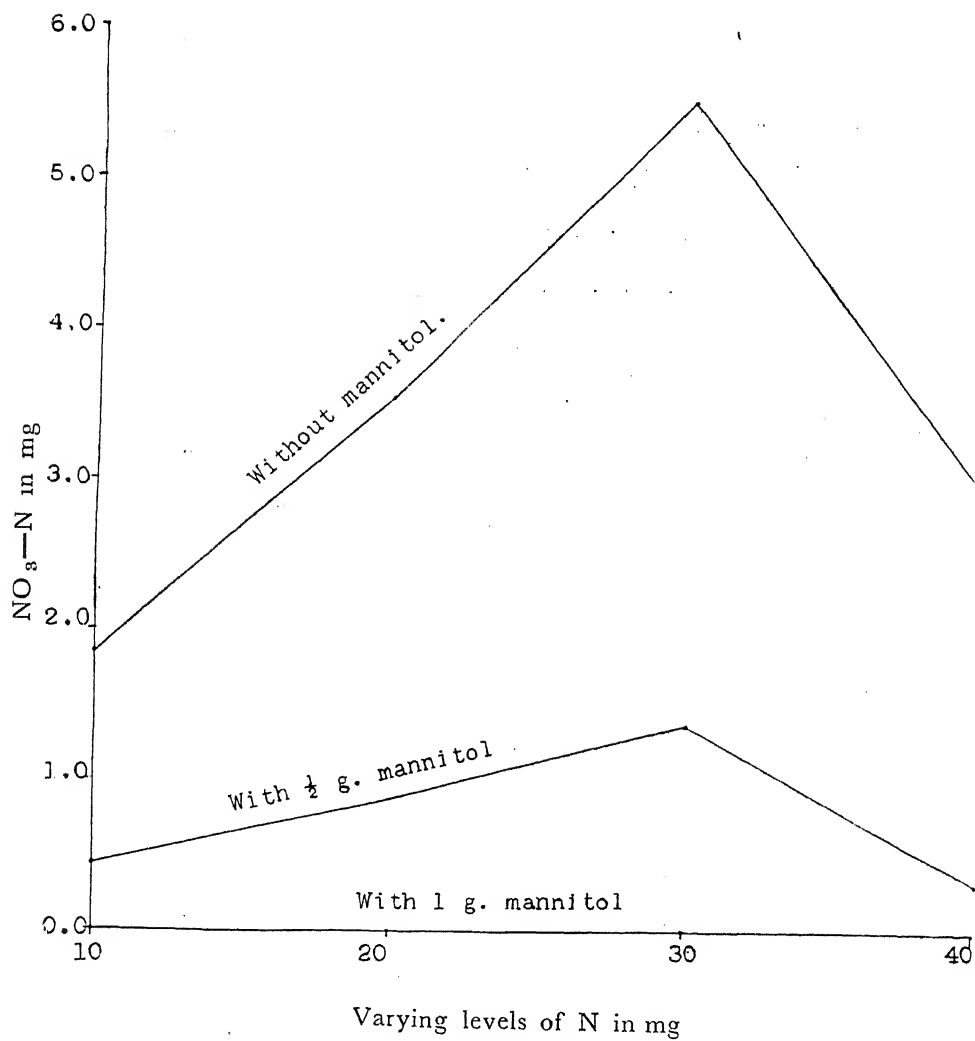
SUMMARY

In order to study the process of nitrification in the presence of organic matter nitrogen was taken in the form of ammonium sulphate at 4 varying levels and mannitol was added as an organic material using sand as the medium. The work furnished a convincing evidence that the presence of organic matter in the medium greatly interfered with the process of nitrification due to the locking up of available N by the organisms which used mannitol as a source of energy. Further, the best nitrate formation was noted at 30 mg level of nitrogen.

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Figure 1
EFFECT OF VARYING CONCENTRATIONS OF MANNITOL
UPON NITRATE FORMATION



UNTERSUCHUNGEN AN STREPTOMYCETEN-SPOREN MIT VERSCHIEDENEN FORMEN

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Unter den Bodenorganismen verdienen die Streptomyceten wegen ihrer antibiotisch wirksamen Stoffwechselprodukte besonderes Interesse. Ausserdem hat diese Mikroorganismengruppe bei der Umwandlung organischer Stoffe im Boden eine grösse Bedeutung, so ist sie z. B. auch am Aufbau der Humusstoffe beteiligt. Die dunkelgefärbten Autolyseprodukte vieler Streptomycetenstämme wurden eingehend untersucht und als huminsäureähnlich bezeichnet, da sie in vielen chemischen und physikalischen Reaktionen den Bodenhuminsäuren entsprechen (F. Scheffer und Mitarbeiter, 1950 ; W. Flaig und Mitarbeiter, 1952a).

Bei ökologischen und physiologischen Untersuchungen an Streptomyceten, wie wir sie in grösserem Rahmen durchführen, stösst man bei der Klassifizierung und Bestimmung neuer Isolierungen immer wieder auf Schwierigkeiten. Wir haben nun versucht, mit einem neuen Untersuchungsschema, das Haferflockenagar als Standardnährboden aufweist, dieser Schwierigkeiten Herr zu werden (W. Flaig und H. J. Kutzner, 1954). Zu diesem Untersuchungsschema gehören neben 12 verschiedenen physiologischen Reaktionen auch morphologische Beobachtungen im Licht- und Elektronenmikroskop.

Schon vor einiger Zeit konnten wir finden, dass mit dem Elektronenmikroskop Feinstrukturen an den Sporen von Streptomyceten zu erkennen sind, die mit dem Lichtmikroskop infolge seines zu begrenzten Auflösungsvermögens nicht zu beobachten waren (W. Flaig und Mitarbeiter, 1952b). Inzwischen wurden diese Untersuchungen auf ein grösseres Material an Stämmen ausgedehnt und die Sporen von 500 Stämmen beobachtet. Dabei gelang es uns bis jetzt, folgende verschiedenen Sporenformen zu finden.

Danach unterscheiden wir Sporen mit rauher und glatter Oberfläche. Je nach Art der Membranauswüchse handelt es sich bei den rauhwandigen Sporen um stachelige, haarige oder warrige Formen. Durch verschiedene Präparationstechnik konnte gezeigt werden, dass es sich bei diesen "Stacheln" und "Haaren" tatsächlich um Auswüchse oder Verdickungen der Membran handelt. So waren z. B. auf Präparaten, die von einer Sporensuspension gewonnen waren, sehr viele abgebrochene und einzeln liegende "Stacheln" und "Haare" zu sehen.

* Anschrift : Braunschweig, Bundesallee 50.

Verschiedene Sporenformen

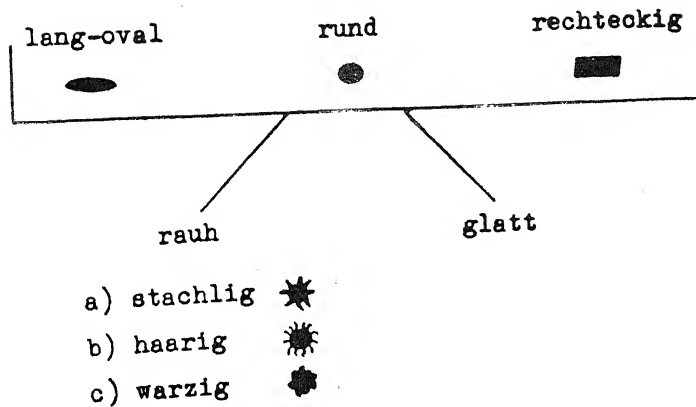


Abb. 1. Verschiedene Sporenformen

Eine Unterscheidung von *rauh* und *glatt* ist sehr leicht zu erkennen, schwieriger wird es bei einer Unterteilung innerhalb der *glattwandigen* Gruppen, da hier zwischen lang-oval, rund rechteckig alle Übergänge vorkommen.

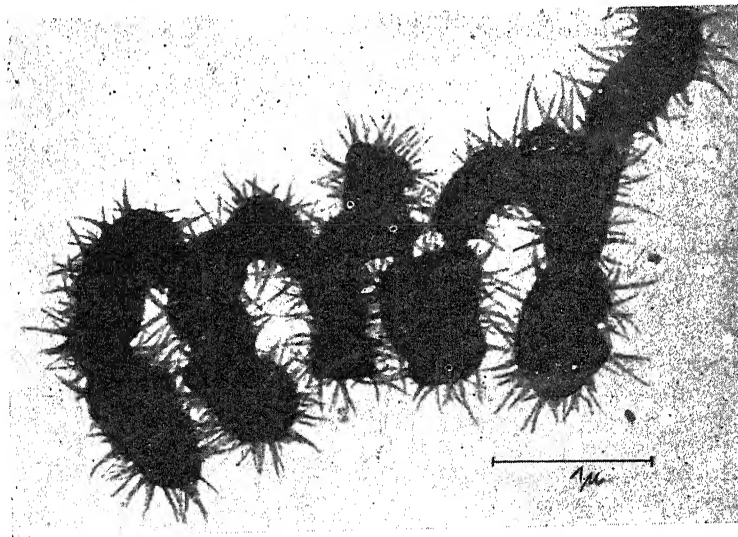


Abb. 2. Stachelige Sporen

Die stacheligen Formen waren am auffallendsten (Abb. 2). Aber auch hier können die Stacheln verschieden lang sein. Stämme mit blaugrauem Luftmycel auf Haferflock-Agar, die also *Strept. viridochromogenes*, nahestehen, besitzen stets Sporen mit kürzeren Stacheln. Anders dagegen verhalten sich einige Stämme aus der *Strept-albus*-Serie, deren Sporen längere, schmale Stacheln besitzen,

Ausserdem kann es bei diesen Stämmen vorkommen, dass auf Nährböden mit Nitrastickstoff die Stachelbildung sehr reduziert ist oder auch ganz fehlen kann. Etwas ähnliches lässt sich bei den sogenannten haarigen Sporen beobachten, wobei die Haare vielleicht nur als eine besonders dünne Abart der Stacheln zu bezeichnen sind.

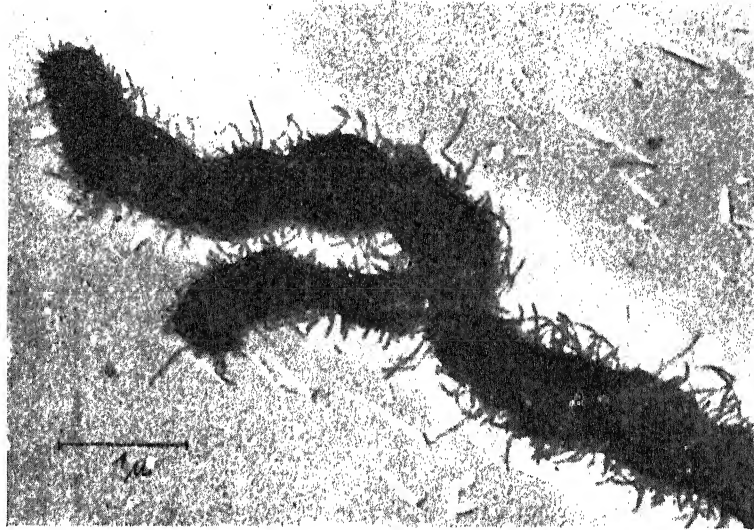


Abb. 3. Haarige Sporen

Diese haarigen Sporen (Abb. 3.) treten nur bei einer kleinen Gruppe von Streptomyces-Stämmen mit weissgrauem Luftmycel auf, die auch physiologisch die gleichen Reaktionen aufweisen, für die wir aber noch keinen definierten Vergleichsstamm gefunden haben. Eine Mittelstellung nehmen Stämme mit grünem Luftmycel ein, die wahrscheinlich zur viridis-Gruppe gehören, bei denen stachelige und haarige Sporen vorkommen. Auch sogenannte "warzige" Sporen, bei denen die Membran-Auswüchse in Form von Höckern oder Warzen auftreten, besitzen nur wenige Stämme mit dunkelgrauem Luftmycel und gelbgrünem Pigment.

Weitaus die Mehrzahl aller untersuchten Stämme hatten glatte langovale Sporen, z. B. *Strept. griseus*, *coelicolor* und viele andere. Auch die Autoren, die schon früher Streptomyces-Sporen mit dem Elektronenmikroskop beobachtet hatten (A. E. Kriss und Mitarbeiter, 1944, P. Carvajal, 1946, 1947, G. Bringmann, 1951) zeigen in ihren Arbeiten nur solche glatten, lang-ovalen Formen. Die sogenannten runden und rechteckigen Sporen, die sich, wie schon gesagt, nur schwer klar von den lang-ovalen differenzieren lassen, treten auch wieder nur bei wenigen Stämmen auf. Zu der Gruppe mit runden Sporen gehört neben *Strept. albidoflavus* eine Reihe gleichartiger Stämme, die sich durch ein gelb graues Luftmycel auf Haferflocken-Agar und besonders durch die Bildung eines blauen Pigmentes auf Kartoffelscheiben auszeichnen. Auch die rechteckigen Sporen sind nur für einige wenige Gruppen von Stämmen charakteristisch.

Bei allen hier beschriebenen Sporen handelt es sich um Sporen endogenen Ursprunges, die vom Luftmycel präpariert sind. Eingehende Beobachtungen über die Sporenbildung, deren einzelne Phasen im Elektronenmikroskop ebenfalls gut erkennbar sind, sind von E. Küster (1953) und W. Flaig und Mitarbeiter (1954/55) beschrieben worden.

Auf Grund unserer Beobachtungen halten wir die Sporenform der Streptomycceten für ein weiteres Charakterisierungsmerkmal dieser Arten, das zusammen mit den üblichen physiologischen Merkmalen eine Einteilung und Bestimmung der Streptomycceten erleichtert. Wesentlich ist es, die Präparation der Sporen nach dem Wachstum auf demselben Nährboden durchzuführen. Wir wandten dabei Haferflockenagar an und erhielten dabei die oben beschriebenen Ergebnisse. Bei einem Vergleich mit Sporen von Kartoffelagar, wie ihn E. Baldacci und Mitarbeiter (1954) als Standard-Nährboden für Streptomycceten anwendet, konnten wir eine volle Übereinstimmung mit Haferflockenagar feststellen (E. Küster und A. Grein, 1954/55). Danach traten also nach Wachstum auf diesen beiden Nährböden keine derartigen Unterschiede in Bezug auf die Sporenform auf, wie wir sie bei einem Wechsel von Haferflockenagar und Nitrat-Agar gefunden hatten.

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SECTION—6 TRACE ELEMENTS IN SOIL

PRELIMINARY STUDIES ON THE MICRO-ELEMENT STATUS OF DELHI SOILS

By

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INTRODUCTION

The geochemical factors controlling the distribution of elements in rocks and rock minerals have been elucidated by Goldschmidt.¹ Goldschmidt's work revealed that ionic charge, size and polarization are responsible for the modes of distribution of the elements in rocks and minerals at the time of their separation from the magmas. In addition there are also geological and petrogenetic factors which control micro-element distribution in rocks. In soil genesis, the parent materials are weathered and transformed into soils by the associated factors climate, vegetation, topography and time. The micro-elements primarily present in the parent materials undergo a new cycle due to the biological factors operative within the soil mass. The distribution of micro-elements, manganese, boron, zinc and copper in some Indian soils have been reported by earlier workers,² (Hoon and Dhawan, 1943 ; Ramamoorthy and Viswanath, 1946 ; Sastry and Viswanath, 1946 ; Dhawan and Dhand, 1950 ; Biswas, 1951 ; Bendale *et al*, 1951).

The parent materials of Delhi soils are the local rocks and alluvium of riverain and aeolian origin. The rocks in Delhi represent but a scattered and improperly developed phase of the Delhi system and consist of dark grey, compact quartzites, with incrustations of yellow metallic pyrite. Heron³ identified in thin sections small amounts of sillimanite in addition to comparatively large quantities of magnetite. The pegmatites, occurring within Delhi area, are coarse, incoherent and loose and contain chiefly quartz, feldspar, minor amounts of biotite and small amounts of tourmaline. Occasionally a light violet coloured clay is usually associated with pegmatites and is probably derived from the alteration of feldspars and mica to some extent.

In order to understand the micro-element status of Delhi soils, their possible origin and distribution in different layers of a profile, a preliminary study of undisturbed soil profiles and parent materials was undertaken and the results are discussed.

EXPERIMENTAL

Soil samples were collected on profile basis from two uncultivated sites on the table land of the Delhi ridges lying north and south of I. A. R. I. Estate. Samples of weathered and apparently unweathered rock were collected. Profile I

(south) showed slight accumulation of calcium carbonate in the lower layers and the internal drainage appeared somewhat restricted. Profile II (north) showed no zone of calcium carbonate accumulation and had a good internal drainage.

The soil samples were analysed by adopting standard methods of analysis. Molybdenum, zinc, copper, manganese and cobalt were determined chemically. Manganese was estimated by the method proposed by Willard and Greathouse,⁴ zinc and copper by Holme's method,⁵ cobalt by the nitroso-R-salt method and molybdenum by the thiocyanate stannous chloride method (Sandell).⁶

RESULTS

Physical and chemical composition of soils.—The data on the mechanical composition, pH and heavy minerals in fine sand fraction is given in table I.

TABLE I

Mechanical Composition of soils

Profile No. and depth in inches	pH	Coarse sand%	Fine sand%	Silt %	Clay %	Heavy minerals in fine sand %
I						
0—3	7.3	12.6	60.0	15.5	9.7	3.40
3—8	7.4	12.9	57.0	16.6	12.6	3.28
8—14	7.7	13.6	53.5	17.0	14.8	2.46
14—23	7.4	11.7	51.4	17.2	17.8	2.51
23—29	7.3	10.2	51.5	18.7	18.0	2.40
29—37	7.8	10.6	49.5	22.0	16.3	1.76
37—45	7.8	29.5	38.7	18.3	12.0	1.41
II						
0—3	7.0	13.4	62.1	15.2	7.6	5.03
3—24	7.5	15.4	52.2	19.1	11.4	3.20
24—36	7.1	27.3	39.2	17.8	10.7	2.35
36—42	7.5	80.2	1.3	12.6	2.5	0.14

In both the profiles the pH values are between 7.0 and 7.8. In profile I (south) the coarse sand is nearly constant, except in the lowest depth, but fine sand content decreases with the depth of the profile, with a parallel increase in the silt and clay contents. Possibly the increase in silt and clay content with the depth of the profile is partly due to secondary weathering of fine sand and partly due to translocation of the fine fractions. The heavy mineral content also shows a gradual decrease with depth. In profile II (north) coarse sand increases while fine sand and heavy mineral contents decrease with depth. The layer 3"—24" shows a slight accumulation of silt and clay. A comparison of the two profiles shows that with the increase in water regime within the solum, more of silt and clay is being formed.

Fusion analysis of the soils is given in table II.

TABLE II
Chemical analysis of soils

Profile No. and depth in inches	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	CaO	MgO	P ₂ O ₅	K ₂ O
I							
0—3	80.61	3.50	9.98	1.10	0.92	0.051	0.31
3—8	80.94	3.89	9.53	1.10	1.38	0.033	0.30
8—14	77.63	4.18	11.39	1.08	1.33	0.035	0.29
14—23	78.70	4.87	10.49	1.19	1.29	0.037	0.29
23—29	80.76	4.29	9.25	1.25	1.44	0.040	0.32
29—37	80.41	4.50	11.39	1.51	1.86	0.038	0.30
37—45	82.30	5.04	8.82	1.50	1.90	0.043	0.29
II							
0—3	83.10	2.59	9.96	1.24	0.87	0.084	0.30
3—24	85.11	2.42	9.62	1.18	0.92	0.063	0.20
24—36	88.57	1.87	8.14	1.10	0.97	0.050	0.26
36—42	95.19	0.93	1.87	0.64	0.71	0.040	0.09

In profile I (south) the silica content is more or less constant in all the layers. The other constituents except potash show a marked tendency to increase with depth. Iron appears to be more mobile and the maximum content is noticed in the last layer. A similar trend is also noticeable in the case of lime and magnesium. Possibly in the lowest depth, part of iron, lime and magnesium are in free forms *i.e.*, not in the silicate complex. Profile II (north) is more siliceous and silica content increases with depth. Iron and the other constituents decrease with the depth of the profile. They are, however, much in excess over the respective values of the constituents present in the weathered layer (36"—42").

Mineralogical composition of clays and sands.—The clays were separated from the soils and analysed. The derived ratios and cation exchange capacities are given in table III.

TABLE III
Clay Constants

Depth	0—3"	3—8"	14—23"	29—37"	37—45"
SiO ₂ /R ₂ O ₃	2.41	2.55	2.42	2.45	2.37
SiO ₂ /Al ₂ O ₃	3.14	3.37	3.11	3.55	3.14
Cation exch. capacity m. e. %	46.0	48.0	45.0	45.5	48.0

The clays contained 1.8 to 2.5% magnesium oxide and 2 to 3% potash. The derived ratios and the cation exchange capacities show that the clays are of the same nature, composed mainly of illite and lesser amounts of montmorillonite.

The percentage composition of the heavy minerals in fine sands is given in table IV.

TABLE IV

Percentage composition of heavy minerals in fine sand fractions

Profile No. and depth in inches	Magne- tite	Horn- blende	Augite	Pyro- xene	Tour- maline	Zoisite	Micas	Zircon	Rutile	Kyanite	Garnet	Sillima- nite
I.												
0-3	30	27	0.7	—	7	1	15	10	3	1	2	1
3-8	40	31	9.0	—	4	1	2	3	2	2	2	3
8-14	32	31	—	2	10	1	2	5	1	3	7	4
14-23	33	30	—	1	9	3	1	13	2	1	4	5
23-29	30	34	—	2	6	—	—	10	2	2	6	6
29-37	32	35	—	1	8	3	2	6	1	1	6	7
37-45	41	18	—	1	9	2	2	11	1	1	4	4
II.												
0-3	31	30	—	—	4	1	21	6	1	1	2	3
3-24	30	15	—	1	5	—	31	11	2	—	2	3
24-36	40	12	—	—	2	—	33	4	3	1	1	4
36-42	50	—	—	—	2	—	43	2	2	—	—	—

The minerals magnetite, mica, tourmaline, zircon and rutile are common in soils and weathered material. The minerals hornblende, pyroxene, augite, kyanite, sillimanite, zoisite and garnet are present only in the soils and not in the weathered zone. Considerable amount of hornblende is present in both the soils. Augite and pyroxene are present prominently in profile I.

Micro-elements in soils.—The micro-elements manganese, zinc, copper, cobalt and molybdenum increase with depth in profile I (table V) and they seem to concentrate in the zone 23"—37" which is also the case with clay and silt (*Cf.* table I).

TABLE V

Micro-element status of Soils (p. p. m.)

Profile No. and depth in inches	Manganese	Zinc	Copper	Cobalt	Molybdenum
I					
0—3	404.1	12.1	13.4	6.9	0.9
3—8	404.6	12.1	13.6	7.9	0.9
8—14	416.6	12.1	14.2	8.9	1.2
14—23	469.8	16.3	20.9	10.0	1.5
23—29	527.1	26.6	21.7	12.1	1.5
29—37	538.7	25.6	21.0	12.1	0.9
37—45	496.6	18.7	20.4	11.5	0.7
II					
0—3	430.4	20.3	18.4	9.9	1.5
3—24	396.0	18.3	19.0	9.3	1.5
24—36	315.0	14.2	16.7	8.9	1.7
36—42	94.1	4.0	8.1	4.6	2.6

In profile II there is a clear tendency for the micro-elements to decrease with depth. However, the variation of the micro-elements in the two profiles is somewhat similar to the elements iron, calcium and magnesium.

DISCUSSION

A knowledge of the micro-element status of the soil is as important as the location of the seat of these elements for the full appreciation of the potential value of a soil. The micro-element contents of different minerals differ and even in the same mineral the amount of any particular element present depends upon their fractional crystallisation from the magmas. It is often suggested that a relationship exists between the minerals in the fine sand fractions and the micro-element status of the soils.^{7,8}

The two profiles studied in the present investigation show similarities in their physical, chemical and mineralogical properties but the constituents including the micro-elements tend to accumulate in the lower layers of profile I and in the top layers profile II. Attention has already been drawn to the trends of accumulation of the micro-elements and the major elements iron, magnesium and calcium between 14—45" in profile I and 0—8" in profile II. This is in accordance with the well-known geochemical association of magnesium, iron, cobalt, zinc and manganese especially in iron-magnesium silicates and iron oxide minerals.

The percentage values (Table VI) of magnetite, hornblende, zircon and tourmaline on soil basis show that the total heavy mineral content as well as magnetite and hornblende decrease with the depth of the profile.

TABLE VI
Percentage of minerals present in soil

Profile No. and depth in inches	Total heavies in soils	Magnetite	Hornblende	Zircon	Tourmaline
I.					
0—3	3.40	1.02	0.92	0.34	0.24
3—8	3.28	1.31	1.01	0.10	0.13
8—14	2.46	0.79	0.76	0.12	0.25
14—23	2.51	0.83	0.75	0.33	0.24
23—29	2.40	0.72	0.82	0.24	0.14
29—37	1.76	0.56	0.62	0.11	0.14
37—48	1.41	0.56	0.25	0.16	0.13
II.					
0—3	5.03	1.56	1.51	0.30	0.20
3—24	3.20	0.96	0.48	0.35	0.16
24—36	2.35	0.94	0.28	0.09	0.05
36—42	0.14	0.07	—	0.003	0.06

On the other hand, relatively hard minerals tourmaline and zircon, though they are irregular in distribution, increase or decrease more or less together in the different layers.

The relative status of boron estimated from the stepped spectra obtained by direct current arc method using copper electrodes (spec-pure) agreed fairly closely with the tourmaline content in most of the layers of profile I. However, the results obtained in general do not permit such correlation between the mineral content and the other micro-elements determined. Clays are known to contribute only small amounts of micro-elements. Further work on these lines with silts and sands to establish a better correlation between the micro-element content and minerals in soils is in progress. Estimation of the micro-element status of pure minerals separated from soils is also being taken up.

SUMMARY

A study of virgin soil profiles near about Delhi was undertaken to establish correlation, if any, between the micro-elements and minerals present in the soils. A mineralogical analysis of fine sands and clays was made. The available data do not show definite relationship between the micro-elements and the minerals present in fine sands.

ACKNOWLEDGMENT

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INFLUENCE OF MOLYBDENUM ON THE GROWTH AND YIELD OF BERSEEM (*TRIFOLIUM ALEXANDRINUM*)

By

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INTRODUCTION

The importance of molybdenum as an essential micro-element for the growth of higher plants¹ and micro organisms² is well-known. The beneficial effect of this element particularly in combination with phosphatic fertilizers has been reported.^{3,4} The effect of boron and molybdenum fertilizers on berseem under field trials was studied at this Institute and a significant influence on fodder, seed and bhusa yields was reported.⁵ As berseem is an important forage crop of Northern India, it is proposed to study how far the use of micro-element would benefit this legume in other soil types of the country. In the first instance molybdenum only is applied with phosphatic fertilizers. The molybdenum status of the soils of our country is not known and no systematic investigation on the uptake of Mo by berseem seems to have been so far made. From this point of view it was considered desirable in the present investigation, to study the relation between the uptake of Mo and the total yield of the crop. The data obtained and statistically analysed in the first year of our trials are recorded and discussed in relation to the contributions made by superphosphate and molybdenum for the growth of the crop.

EXPERIMENTAL

Berseem does not seem to be popular on black cotton soils though the soils are known for their inherent fertility. Black cotton soil from Nagpur was selected at the first instance and experiments were planned under controlled conditions of pot culture. Side by side, experiments with Delhi soil under similar treatments were also carried out. The black cotton soil (0—9") was obtained from Government Experimental Farm, Nagpur. The soil was from a rabi field in which wheat was being grown for three years without the addition of fertilizers prior to collection of the sample. The Delhi soil was collected from Middle Block C-4, I. A. R. I. Farm, New Delhi. Earthenware pots of 30 lbs capacity were selected for the experiment. Soils in 28 lbs lots were weighed out, thoroughly mixed with fertilizers, moisture made up to one-third the saturation capacity of the soils and potted. There were in all, six treatments including control as follows :—

(1) Superphosphate @ 80 lbs P_2O_5 + 2 lbs MoO_3 per acre, (2) Superphosphate @ 80 lbs P_2O_5 per acre, (3) Superphosphate @ 40 lbs P_2O_5 + 2 lbs MoO_3 per acre, (4) Superphosphate @ 40 lbs P_2O_5 per acre, (5) Lime @ 1 metric ton per acre, and (6) Control. A basal dressing of nitrogen @ 10 lbs per acre in the form of ammonium sulphate was given in all cases. Sowing was done on 23-11-53.

Germination was satisfactory in all the pots and when the seedlings nicely established, 12 plants were maintained per pot all through the experiments. There were five replicates for each treatment. The pots were randomised according to Fisher.⁶ Observations on agronomic characters of the plants such as height and tillering were taken at intervals. The crop afforded four cuttings, the first one being taken after 58 days from the date of sowing and the rest at about a month's interval. At this place mention may be made that prior to the fourth cutting the plants in almost all the pots under different treatments contacted root diseases and were insect-infested with the consequence that a number of plants in some of the pots died vitiating the actual yield of the crop for the fourth cutting and therefore the yield data for the fourth cutting was omitted. The mechanical analysis of the soils was done by International method as modified by Robinson.⁷ Available K_2O and P_2O_5 were estimated by Dyer's method.⁸ Molybdenum was estimated by stannouschloride-thiocyanate method.⁹ The rest of the estimations were done according to Piper.¹⁰

RESULTS

The two experimental soils were analysed for mechanical constituents, major nutrients and molybdenum and the results are given in Tables I and II.

TABLE I
Mechanical composition of Black Cotton Soil and Delhi soil

Soil	Moisture %	Loss on igni- tion %	Clay %	Silt %	Fine sand %	Coarse sand %
Black cotton soil	6.83	2.89	53.72	25.48	9.97	1.51
Delhi soil	1.38	0.44	13.56	8.36	74.92	—

TABLE II
Chemical composition (oven-dry) of Black Cotton Soil and Delhi soil

Soil	pH	Water sol. salts %	Nitrogen %	HCl soluble			A available			Mo p.p.m.
				Ca(O) %	Mg(O) %	K ₂ (O) %	P ₂ O ₅ %	K ₂ (O) %	P ₂ O ₅ %	
Black cotton soil	7.4	0.21	0.064	2.16	1.02	0.71	0.06	0.028	0.0019	1.5
Delhi soil	8.4	0.12	0.060	0.42	—	0.44	0.07	0.019	0.02	1.0

The mechanical analysis reveals that Delhi soil is a sandy loam and the black cotton soil is characterised by a considerably high content of clay (53.7%). From the chemical composition (table II), it is evident that black cotton soil has a higher fertility status compared to Delhi soil, excepting that the phosphate content particularly the available form in black cotton soil (0.0019%) is much less than in Delhi soil (0.02%). The molybdenum content of Delhi soil is round 1 p. p. m. and of black cotton soil 1.5 p. p. m.

The growth observations (*e.g.*, height and tillering) noted before each cutting are recorded in Table III.

TABLE III

Growth data of Berseem raised in pots in black cotton soil and Delhi soil under different treatments
(All the results recorded are the average values of the observations)

Treatment	Black cotton soil						Delhi soil					
	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	Third cutting
	No. of tillers per plant in cm	Ht. per plant in cm	No. of tillers per plant in cm	Ht. per plant in cm	No. of tillers per plant in cm	Ht. per plant in cm	No. of tillers per plant in cm	Ht. per plant in cm	No. of tillers per plant in cm	Ht. per plant in cm	No. of tillers per plant in cm	Ht. per plant in cm
Superphosphate @ 80 lbs												
P ₂ O ₅ + 2 lbs MoO ₃ /acre.	No tillering	3.62	2.04	15.96	3.04	23.84	No tillering	9.38	2.26	25.34	2.14	25.34
Superphosphate @ 80 lbs P ₂ O ₅ per acre	"	2.48	1.42	10.90	3.24	22.70	"	8.66	2.42	21.62	2.24	21.62
Superphosphate @ 40 lbs. P ₂ O ₅ + 2 lbs MoO ₃ /acre	"	2.96	1.64	14.22	3.26	23.84	"	8.96	2.22	24.30	2.04	24.30
Superphosphate @ 40 lbs P ₂ O ₅ per acre	"	2.10	1.00	6.22	2.12	14.28	"	6.54	2.38	24.72	2.54	24.72
Lime @ 1 metric ton/acre	"	1.90	1.00	3.54	1.36	8.34	"	3.66	2.10	18.73	2.42	18.78
Control	"	2.18	1.00	3.78	1.46	7.18	"	5.80	2.26	22.88	2.18	22.80
"P" test	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	Not sig.	highly sig.	Not sig.	Not sig.
C. D. @ 5%	0.62	0.47	2.72	0.55	5.08	1.36	—	2.83	—	—	—	—
C. D. @ 1%	0.83	0.64	3.68	0.75	6.88	1.84	—	3.83	—	—	—	—

The observations on growth (*e.g.*, plant height and tillering) were recorded just prior to each cutting. The average number of tillers and average height per plant were calculated on the basis of 12 plants per pot and five replicates under each treatment. It will be seen from table III that in black cotton soil prior to the first cutting molybdenum combined with phosphate at 80 lbs level has significantly enhanced the growth of plants over all other treatments and molybdenum with 40 lbs level of phosphate had significantly influenced the growth over the treatment of 40 lbs level of P_2O_5 , lime and control but showed statistically equivalent effect to 80 lbs level of P_2O_5 even though produced plants of numerically greater heights. Prior to the second cutting molybdenum-phosphate combinations at both levels of phosphate showed significant influence (*i.e.*, enhancement) on growth. Prior to the third cutting molybdenum with both levels of phosphate had better growth than other treatments but statistical significance failed in case of 80 lbs level of phosphate.

In Delhi soil, however, the superiority of phosphate-molybdenum combination over phosphate alone in promoting growth is doubtful even though some significance in plant heights were observed in the first two cuttings; the effect of treatments was non-significant with respect to tillering.

Yield data of berseem obtained in black cotton soil are given in table IV. The relative influence of the treatments on the growth of berseem just before the 1st cutting may be seen in plate 1.

Green matter yield of berseem grown in black cotton soil (table IV) was significantly higher under the treatment of phosphate-molybdenum combinations at 80 lbs P_2O_5 level in all the three cuttings and the three cuttings combined than under any other treatment. Phosphate-molybdenum combination at 40 lbs P_2O_5 level had been statistically superior to 40 lbs level of phosphate alone. Even though this combination had given numerically superior total yield over that obtained with 80 lbs level of phosphate, statistical significance was lacking. Considering the dry weight yield, similar trend of influence of treatments was noticed in the first two cuttings, but in the third cutting the effect of phosphate-molybdenum combinations statistically equalised 80 lbs P_2O_5 level but was significantly superior to other treatments including 40 lbs level of phosphate. When the total dry matter yield of the three cuttings was taken into account, numerical superiority of phosphate-molybdenum at 80 lbs P_2O_5 level was observed but statistical significance lacked.

The yield data obtained on Delhi soil is given in table V.

In Delhi soil, lime treatment had shown a depressing effect although it was expected that the amendment would improve the crop growth by making more of molybdenum available at higher pH resulting from its incorporation. Molybdenum did not show significant response over phosphate alone in any of the three cuttings or all the cuttings combined in the soil type of Delhi.

Average molybdenum contents of the berseem samples of the different cuttings under different treatments are given in table VI. Though the yields of berseem were not significantly influenced by Mo treatment in Delhi soil, the average Mo content in the samples of the third cutting where maximum uptake was expected, was also estimated and the results are recorded in table VI.

TABLE IV

Average green and dry weight yield of berseem per pot raised in black cotton soil under different treatments

Treatment	First Cutting		Second Cutting		Third Cutting		Total of three Cuttings	
	Green wt. yield in gms	Dry wt. yield in gms	Green wt. yield in gms	Dry wt. yield in gms	Green wt. yield in gms	Dry wt. yield in gms	Green wt. yield in gms	Dry wt. yield in gms
Superphosphate @ 80 lbs P_2O_5 + 2 lbs MoO_3 per acre	6.26	0.92	51.14	6.08	100.04	11.64	157.44	18.64
Superphosphate @ 80 lbs P_2O_5 per acre	2.62	0.42	27.70	2.98	86.60	11.42	116.92	14.82
Superphosphate @ 40 lbs P_2O_5 + 2 lbs MoO_3 per acre	3.56	0.52	36.58	3.98	80.00	9.42	120.14	13.92
Superphosphate @ 40 lbs P_2O_5 per acre	0.86	0.20	9.42	1.10	46.94	5.56	57.22	6.86
Lime @ 1 metric ton per acre	0.38	0.12	2.80	0.34	13.48	1.50	16.66	1.96
Control	0.56	0.12	2.74	0.34	10.86	1.42	14.16	1.88
"F" test	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.
C. D. @ 5%	2.24	0.31	13.29	1.47	20.78	2.75	36.01	4.03
C. D. @ 1%	3.03	0.42	18.01	2.00	28.16	3.37	48.80	5.46

TABLE V

Average green and dry weight yield of berseem per pot raised in Delhi soil under different treatments

Treatment	First Cutting		Second Cutting		Third Cutting		Total of three Cuttings	
	Green wt. yield in grams	Dry wt. yield in grams	Green wt. yield in grams	Dry wt. yield in grams	Green wt. yield in grams	Dry wt. yield in grams	Green wt. yield in grams	Dry weight yield in grams
Superphosphate @ 80 lbs P_2O_5 + 2 lbs MoO_3 per acre	24.72	3.04	58.04	6.80	54.40	7.26	137.16	17.10
Superphosphate @ 80 lbs P_2O_5 per acre	24.50	2.86	55.52	6.22	57.52	7.52	137.54	16.60
Superphosphate @ 40 lbs P_2O_5 + 2 lbs MoO_3 per acre	20.02	2.52	59.16	7.08	56.72	7.92	135.90	17.52
Superphosphate @ 40 lbs P_2O_5 per acre	17.96	2.24	65.62	7.60	74.42	10.64	158.00	20.48
Lime @ 1 metric ton per acre	6.32	0.78	36.64	3.48	37.42	4.38	80.38	8.64
Control	11.46	1.44	53.04	6.00	59.40	8.34	123.90	15.78
'F' test	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.	highly sig.
C. D. @ 5%	4.02	0.55	10.47	1.33	14.62	2.41	24.34	3.83
C. D. @ 1%	5.44	0.75	14.19	1.80	19.82	3.27	32.99	5.19

TABLE VI

Molybdenum content in p.p.m. D. M. of berseem raised in black cotton soil and Delhi soil under different treatments

Treatment	Black cotton soil Cutting			Delhi soil Cutting
	First	Second	Third	Third
Supherphosphate @ 80 lbs P_2O_5 per acre	0.3	0.4	0.3	0.4
Superphosphate @ 80 lbs P_2O_5 + 2 lbs MoO_3 /acre	2.1	3.4	9.0	36.0
Superphosphate @ 40 lbs P_2O_5 per acre	0.3	0.3	0.8	1.3
Superphosphate @ 40 lbs P_2O_5 + 2 lbs MoO_3 /acre	2.3	2.9	9.6	26.4
Lime @ 1 metric ton/acre	0.3	—	0.2	—
Control	0.5	0.9	1.0	0.2

From the above table it would be seen that the Mo uptake by berseem under the treatment of the element (Mo) was higher than the untreated ones. The Mo content of the plants not treated with the element varied from 0.3 to 1.0 p.p. m. and of the treated plants from 2.1 to 9.6 p.p.m. in black cotton soil.

DISCUSSION

The yield of berseem on the black cotton soil is highly significant in all the treatments with the phosphate fertilizer applied. At 40 lbs level of P_2O_5 added, the yield was four times over the control while at 80 lbs level, the yield increased by eight folds. With the addition of Mo, the average increase in yield at 40 lbs level of P_2O_5 was about 100 % while at 80 lbs level the increase was only about 33 %. Though the effect of Mo can thus be separated from that of the phosphate added, increasing doses of phosphate do not seem to allow the full display of the effect of Mo. Irrespective of the level of phosphate added, Mo seems to accelerate the growth of berseem more in the earlier cuttings than in the later ones. This is evident from the fact that at 40 lbs level the ratio of the yield of berseem with and without Mo in the first three cuttings worked out as 4.1, 3.9 and 1.7 respectively while at 80 lbs level the values were 2.4, 1.8 and 1.2.

Delhi soil, on the other hand, does not seem to respond to the Mo treatment. Even the phosphate that is applied to this soil did not give significant increase in yields; a higher dosage on the contrary showed a decreasing tendency in the yields. The enormous response in black cotton soil and the very poor display in the Delhi soil indicated by superphosphate applied is perhaps due to the differences in the available phosphate contents, the former having 1/10th the phosphate content available in the latter. As the Mo contents of both the soils are nearly of the same order the non-significance of the yields obtained in Delhi soil with the Mo treatment is presumably due to the saturation level of phosphorus available in it.

Though feeding experiments should indicate the exact limits of toxicity of molybdenum present in feeds under Indian conditions it has been reported that molybdenum above 20 p.p. m. D. M., in animal feeds is toxic depending on

the copper content of the diet.¹¹ Addition of P_2O_5 fertilizer alone though increased the yield of berseem grown in black cotton soil did not enhance the intake of molybdenum. Under phosphate-molybdenum combinations, however, the uptake of molybdenum was considerably increased even in the first cutting of the berseem. With subsequent cutting Mo content though further increased showing a maximum of 9.6 p.p. m. in the third cutting was well within the toxic limit. A similar cutting of berseem (3rd cutting) grown in Delhi soil where Mo had not shown significant response, had a higher content of Mo; the maximum value of 36 p.p. m. recorded being much above the toxic limit. It thus appears that black cotton soil has a great tolerance for molybdenum fertilizers while its application is perhaps unnecessary on Delhi soil. The higher content of molybdenum in berseem grown in Delhi soil compared to that grown on black cotton soil may partly be due to the difference in their pH values. It may also be possible that the high clay content and organic complex present in black cotton soil would reduce the availability of molybdenum to the plant due to fixation.

A knowledge of the optimum dosages of both superphosphate and molybdenum required by berseem grown in black cotton soils, keeping in view the yields and the economic factors is desirable. Further, the effects of molybdenum as separated from those of phosphorus can only be studied in a soil where both these fertilizers respond. As black cotton soil provides these conditions further studies with these objectives in view are in progress.

SUMMARY

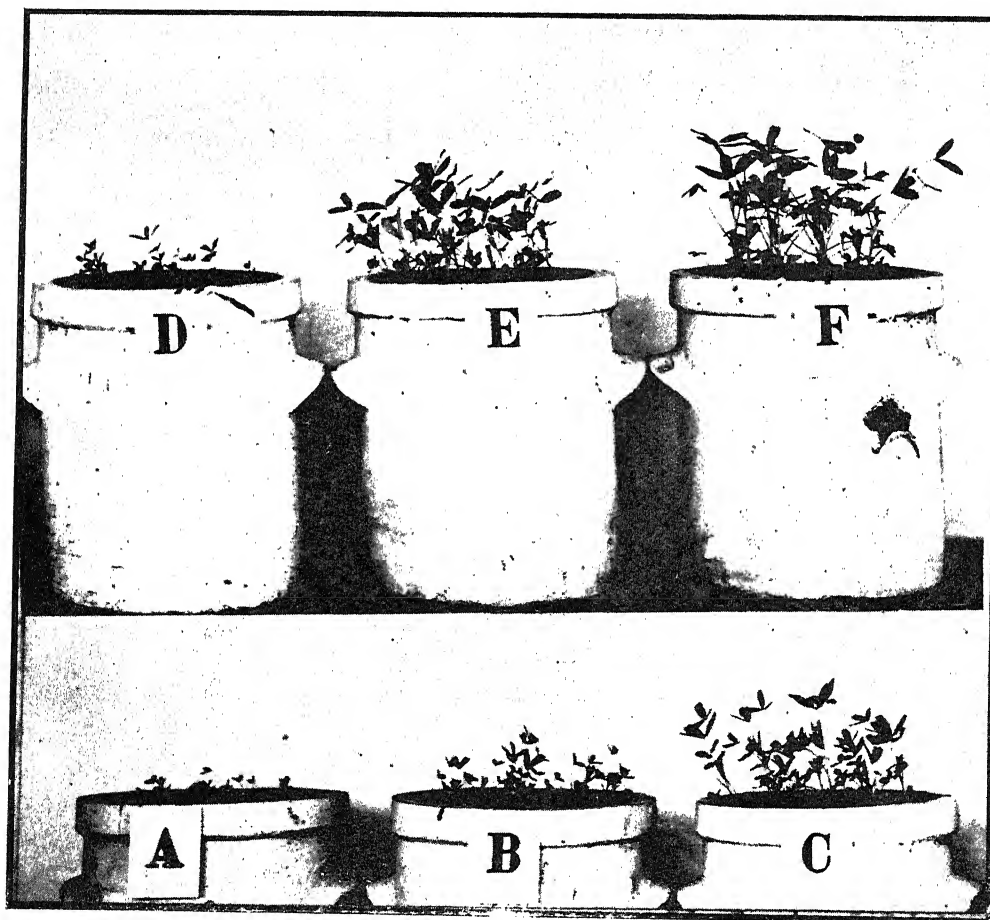
Influence of molybdenum when added along with superphosphate on the growth and yield of berseem raised in pots in Delhi soil and black cotton soil (from Nagpur) was studied. Both superphosphate and molybdenum gave significant yields when used on black cotton soil and the effect of molybdenum over that of the superphosphate could be separated. At 40 lbs level of P_2O_5 added the yield was four times over the control while at 80 lbs level the yield increased by eight folds. With the addition of 2 lbs MoO_3 per acre the average increase in yield at 40 lbs level was 100 % while at 80 lbs level the increase was only 33 %. The maximum molybdenum content in the berseem grown on this soil under molybdenum treatment was 9.6 p.p.m. D. M., well within the toxic limit while the value ranged between 0.3 to 1.0 p.p. m. in the untreated ones. On Delhi soil, berseem did not significantly respond either to the superphosphate or the molybdenum added. On the other hand the maximum molybdenum content of berseem grown with the mixed fertilizers was about 36 p.p. m. D. M. much above the toxic limit. The response and uptake of molybdenum by berseem were discussed in relation to the fertility status of the soils.

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Relative influence of phosphate and molybdenum treatments on the growth of berseem in black cotton soil about two months after sowing.

A. Control
D. Lime

B. 40 lbs P_2O_5
E. 40 lbs P_2O_5 + 2 lbs MoO_3

C. 80 lbs P_2O_5
F. 80 lbs P_2O_5 + 2 lbs MoO_3

A STUDY OF THE MAIN EFFECTS AND INTERACTIONS OF
DIFFERENT MICRONUTRIENTS—B, Cu, Mn, AND Zn—
BY A FACTORIAL DESIGN FIELD EXPERIMENT

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INTRODUCTION

In a previous pot culture experiment we studied the effect of the addition of copper salt to the soil, in presence and absence of added organic manure, on the yield of wheat crop. We found that the increase in crop due to addition of copper salt was 35.8%, while the combination of organic manure and copper salt gave an increase of 118.3% the increase in crop due to the addition of organic manure singly being only 23.3% over the control. From the analysis of variance of the data of crop yields it was evident that both the main effects attributable to copper salt and to organic manure, as well as, the interaction between the two fertilizers were statistically significant.

In a second pot culture experiment of a factorial design, we studied the main effects of and interactions with regard to other two micronutrients *viz.*, zinc and boron. In this experiment we observed that the interactions between organic manure and the two micronutrients were also statistically significant, and simultaneous addition of organic manure and the micronutrients was more beneficial to crop than the addition of the fertilizers singly. It was further noted that simultaneous addition of the two micronutrients to the soil was very much harmful to the plants and resulted in decreasing the crop yield. This negative interaction between the two micronutrients was found also to be statistically significant.

The addition of the micronutrients used in the above experiments probably affects the growth of plants in different ways depending upon a number of factors such as the presence or absence in the soil, not only of the added micronutrient, but also of other micronutrients, presence of a sufficient amount of organic matter in the soil, as well as the actual requirement of the crop for the micronutrient under trial. In view of the effects of interactions both positive and negative between the fertilizers on the crops observed in the results of the two pot culture experiments, described above, it was proposed to carry out a field scale statistical experiment of factorial design with the four micronutrients, Cu, Zn, Mn, and B, both in the presence and absence of organic manure, along with all possible permutations and combinations of the five factors for a study of the main or average effects of the five factors and of the various possible interactions among these five factors.

Modern researches in biochemistry have definitely shown that some of the micronutrients, if not all, are essential for the formation of organic complexes such as plant enzymes and thereby they not only effect oxidation reaction processes of plant growth but possibly they also help in increasing the plant hormones, which ultimately result in giving better yields of crop or eradicating any symptoms of diseases in plants, originating from non-availability of these micronutrients, to the plants from the soil. Since these micronutrients are thus found to take an effective part in the metabolic processes in plants, it would be more appropriate to consider them together and investigate their effects on plant growth when all of them are added together to the soil or in combination with one another and also study their separate individual effects when each of the micronutrient is applied to the soil singly by itself. Such an investigation as proposed by us will show us not only the effects of the interactions of the different micronutrients in plant growth and as a consequence on crop yields, but also their individual main effects and naturally the investigation will have a greater practical value than merely a study of the effects of each one of the micronutrients added singly to the soil.

EXPERIMENTAL

A uniform level piece of land from the field at Taloda in west Khandesh district was selected for the experiment. The experimental area of 20 yds breadth and 400 yds length, was divided into three rows or blocks. The three blocks lay side by side with a distance of two feet separating them from one another. Each block was divided into 48 plots and each plot measure 6 yds in length and 3 yds in breadth. The distance between the two plots in each one of the blocks was two feet. The size of the experimental unit plot was 18 sq yds only. This miniature size employed in the present experiment was specially suitable for the micronutrient fertilizers, since a very small quantity of them was required to be uniformly distributed in the soil of the experimental plot. The effect of intermixing of treatments at the boundary portions could be eliminated by cutting out separately the plants grown in the strips of two feet width separating the plots receiving different treatments. The assignment of plots for different treatments in each of the blocks was made by randomisation. The yield of crop in the 18 sq yds of each plot could fairly represent the effect due to the treatments given to the plot.

The single treatments that we tried were (1) No treatment as control designated as 0, (2) Organic manure—(a) Oil free groundnut cake being used on the basis of 100 lb N per acre, (3) Copper was used in two dosages at two levels, the small dose b_1 being 28 lb copper sulphate per acre, and the large dose b_2 being 56 lb copper sulphate per acre, (4) Zinc—(d) was added as zinc sulphate at the rate of 28 lb per acre. Manganese—(e) was added as manganese sulphate at the rate of 14 lb per acre, and Boron—(f) was added as boric acid, also at 28 lb per acre. The quantities of the different micronutrients used were chosen arbitrarily. The total number of treatments with the five factors, one of them being used at two levels, was, therefore 48.

The different treatments were given to the plots four days before the actual sowing of the *Jowar* seeds. The same quantity of seed by weight was sown in each of the plots in the three blocks. The crop was allowed to grow to the full and was harvested. The yield of grain of *Jowar* obtained from the different plots were weighed and noted and the weights are given in table No. 1 given at the end. During the conduct of the experiment crop in nine plots in all, from

the three blocks, was damaged due to cattle and flooding in rains and reliable date of actual yields from these plots were not available. Figures for these nine plots were therefore obtained by the standard statistical technique for missing values, and these have been substituted as is normally done in such cases in table No. 1, for the respective crop yields. The substituted figures are marked in heavy types in the table.

DISCUSSION

The data of crop yields was statistically analysed and it was found that "F" value for treatment variance as well as for block variance is significant at 1% level. The analysis of variance is given in table No. 2. For comparison of the several treatments, S. E., and C. D. at 5% level were calculated. The values obtained are S. E.=0.697, C. D.=1.961.

It may be seen from an examination of the mean crop yields that out of the six single fertilizer treatments, two, viz., organic manure (a), and copper sulphate in the larger dose (b) have increased the yield appreciably. The following 11 treatments have given significantly higher yields than the control : ab_2 , ab_2def , ab_2df , ab_1def , ade , ab_1 , ab_2f , ad , a , ae , b_2ef . This means that organic manure alone and in the nine different combinations is significantly beneficial for the crop. For studying the significance of the average or main response to the five factors and their interactions, the sum of squares for treatment variance was further analysed and the results are given in table No. 3, where figures marked with single asterisks indicate significance at 5% level while double asterisks indicate significance at 1% level.

A full discussion of all the results of statistical analysis obtained in this experiment is beyond the scope of this paper, nor is it expected to interest the average general reader or students of practical agriculture. It is, therefore, proposed to limit ourselves to a statement of the general indications and conclusions arrived at by statistical analysis.

From the analysis of variance it may be observed that the main or average effect of organic manure is very very large and beneficial for crop. An important feature of these results is that the main effect of only one—Cu—of the four micronutrients is seen to be favourable for the crop and is statistically highly significant. Even though the main effect of each of the other three micronutrients—Zn, Mn, and B—is harmful, but statistically not significant, the interactions between these when added together are generally found to mitigate their harmful effects (when added singly), and are statistically highly significant. In this experiment, some three and four factor interactions between the fertilizers are found to be statistically highly significant, which leads to the conclusion that the effects of the micronutrients vary a great deal according to the presence and absence of the other fertilizer factors under study.

GENERAL CONCLUSIONS

1. The average effect of organic manure, as well as of Cu on the *Jowar* crop is favourable and statistically highly significant, while the average effect of none of the three micronutrients—Zn, Mn, and B—is seen to be beneficial or significant.
2. The absence of all the three factors—Zn, Mn, and B—gives better crop yields than the presence of any one, two or all the three of them. Nevertheless,

their presence either singly or in combination of two and two, is much worse than presence of all the three together.

3. It may be observed that Cu plays a peculiar part in mitigating the harmful effects of Zn, Mn, and B.

4. Boron has adverse effect with organic manure. This adverse effect operates and is marked when any of the other three micronutrients is absent.

5. Manganese is found to counteract the beneficial effect of Cu. This adverse effect of Mn, is operative only in presence of organic manure and in the absence of Zn.

TABLE 1

Yield of Jowar grain in pounds per plot

Treatments	Yield of grain in lb per plot			Total	Mean
	Block I	Block II	Block III		
1. 0	4.5	3.0	3.0	10.5	3.5
2. a	8.0	4.5	6.0	18.5	6.16
3. b ₁	4.5	3.5	2.0	10.0	3.33
4. b ₂	6.0	6.0	4.0	16.0	5.33
5. d	4.0	1.5	2.0	7.5	2.5
6. e	3.0	3.0	2.0	8.0	2.66
7. f	4.0	4.0	2.0	10.0	3.33
8. ab ₁	7.5	7.0	7.0	21.5	7.17
9. ab ₂	9.0	10.0	12.0	31.0	10.33
10. ad	7.0	6.1	6.0	19.1	6.37
11. ae	4.0	6.0	8.0	18.0	6.0
12. af	3.0	3.0	2.6	8.6	2.87
13. b ₁ d	2.0	1.5	1.5	5.0	1.66
14. b ₁ e	3.0	3.0	5.0	11.0	3.66
15. b ₁ f	4.5	1.5	1.5	7.5	2.5
16. b ₂ d	3.3	2.0	3.0	8.3	2.76
17. b ₂ e	3.0	3.0	1.5	7.5	2.5
18. b ₂ f	5.0	4.0	4.1	13.1	4.36
19. de	4.0	3.0	2.0	9.0	3.0
20. df	3.0	4.5	4.0	11.5	3.83
21. ef	1.5	2.0	1.0	4.5	1.5
22. ab ₁ d	6.0	4.0	3.0	13.0	4.33
23. ab ₁ e	5.0	4.4	4.5	13.9	4.63

Yield of grain in lb per plot						
Treatments	Block I	Block II	Block III	Total	Mean	
24. ab ₁ f	4.5	3.0	3.0	10.5	3.5	
25. ab ₂ d	3.0	2.0	3.0	8.0	2.66	
26. ab ₂ e	4.0	3.0	3.0	10.0	3.33	
27. ab ₂ f	9.0	7.0	4.0	20.0	6.66	
28. ade	7.7	7.0	6.9	21.6	7.2	
29. adf	3.0	2.0	1.5	6.5	2.16	
30. aef	4.0	6.0	4.5	14.5	4.83	
31. b ₁ de	4.0	2.0	1.5	7.5	2.5	
32. b ₁ df	2.0	4.0	1.5	7.5	2.5	
33. b ₁ ef	3.0	1.5	1.0	5.5	1.83	
34. b ₂ de	4.0	4.5	6.0	14.5	4.83	
35. b ₂ df	3.0	1.5	1.5	6.0	2.0	
36. b ₂ ef	7.5	4.0	5.0	16.5	5.5	
37. def	3.0	3.0	4.5	10.5	3.5	
38. ab ₁ de	4.0	7.0	4.5	15.5	5.16	
39. ab ₁ df	3.0	1.5	1.5	6.0	2.0	
40. ab ₁ ef	4.0	1.5	2.0	7.5	2.5	
41. ab ₂ de	5.0	3.0	4.0	12.0	4.0	
42. ab ₂ df	8.0	9.0	11.0	28.0	9.33	
43. ab ₂ ef	3.0	5.0	3.0	11.0	3.66	
44. adef	5.3	4.5	4.5	14.5	4.67	
45. b ₁ def	3.0	1.5	4.5	9.0	3.0	
46. b ₂ def	5.8	4.0	6.0	15.8	5.26	
47. ab ₁ def	9.0	7.0	6.0	22.0	7.33	
48. ab ₂ def	11.0	5.0	7.5	23.5	7.83	
Total	227.6	190.0	189.1	606.7	4.21	

o : No treatment, control
a : Organic manure
b₁ : Copper, small dose
b₂ : Copper, large dose

d : Zinc
e : Manganese
f : Boron

(figures in heavy types represent the substituted values)

TABLE 2

Analysis of Variance				
Source of variation	D.F.	S.S.	M.D.	F.
Between treatments	47	586.25	12.4700	8.55**
Between Blocks	2	20.12	10.0600	6.90**
Error	85	123.89	1.4575	
Total	134	730.26		

TABLE 3

Analysis of Variance

(for detecting significance or response of different factors
and their interactions)

Source of variation	D.F.	S.S.	M.S.	F
A	1	140.6200	140.6200	96.48**
B	2	51.4926	25.7463	17.66**
D	1	0.0850	0.0850	0.0583
E	1	0.0010	0.0010	0.0007
F	1	5.1000	5.1000	3.4990
AB	2	0.1595	0.7970	0.0540
AD	1	0.0852	0.0852	0.0580
AE	1	1.2292	1.2292	0.8430
AF	1	7.2451	7.2451	4.9709*
BD	2	2.8185	1.4092	0.9660
BE	2	11.8783	5.9391	4.074*
BF	2	40.7002	20.3531	13.96**
DE	1	66.8315	66.8315	45.85**
DF	1	30.5258	30.5258	20.94**
EF	1	10.7265	10.7265	7.359**
ABD	2	1.8894	0.9424	0.6460
ABE	2	46.1918	23.0959	15.846**
ABF	2	27.6133	13.8066	9.472**
ADE	1	5.7991	5.7991	3.978*
ADF	1	10.7654	10.7654	7.386*
AEF	1	5.1747	5.1747	3.5500
BDE	2	14.4752	7.2367	4.965**
BDF	2	11.7153	5.8576	4.018*
BEF	2	1.7371	0.8685	0.5950
DEF	1	2.3757	2.3757	1.6290
ABDE	2	8.0411	4.0205	2.7580
ABDF	2	45.4562	22.7218	15.593**
ABEF	2	14.1539	7.0819	4.858**
ADEF	1	0.3318	0.3318	0.2270
BDEF	2	17.3872	8.6936	5.964**
ABDEF	2	3.6400	1.8200	1.2480
ERROR	85	123.8900	1.4575	...

STUDY OF MANGANESE IN SOIL PROFILES

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Along with the rapid progress in the domain of trace-elements in relation to the nutrition of plants and animals, chemistry of these elements is also assuming greater importance and receiving more attention. This is more so with manganese, an important member of this group of trace-elements. Since Leeper, (1947) pointed out the intimate association of manganese in soil with the soil forming processes, the study of manganese in soil profiles is receiving greater attention. In a previous communication (Biswas, 1953), some profiles of typical Indian soils were studied for the distribution of different forms of manganese. In that study only one profile represented a locality or station. The present investigation was taken up and made a more detailed one by selecting a few profiles from a particular area representing a well-known group of soils of India

MATERIALS AND METHODS

The materials for this study consisted of few profiles from black cotton soil zone in Jubbulpore, M. P. ; calcareous alluvial soil of the Botanical Sub-station, Pusa, Bihar, alluvial soil of Bhadrak Military Farm, Lucknow ; desert or semi-arid soil of the farm area of the Indian Agricultural Research Institute, New Delhi. The characteristics of Pusa soils are discussed by Desai and Sen (1953). Soil profiles from Jubbulpore were collected by Dr. R. V. Tamhane, Soil Survey Officer of this Institute whereas the others were collected by the members of the staff of this division from time to time.

Total manganese in soil was determined by the method of fusion with potassium bisulphate (Wright, 1939) and for other forms of manganese, the method of Leeper as modified by Sherman, McHargue and Hodgkiss, (1942) was followed. In all subsequent stages, manganese was estimated by the well-known periodate method in sulphuric acid or phosphoric acid medium. The data on pH, CaCO_3 and mechanical analysis are taken from published or unpublished data of this division.

RESULTS AND DISCUSSION

Data on different forms of manganese (water soluble, exchangeable, and active, and total) in different horizons of the profiles are presented separately in groups of soils and are discussed. Active manganese mentioned here is the sum of water soluble, exchangeable, and reducible manganese.

Black soil profiles from Jubbulpore.—As is well-known, these soils are characterised by their high clay content. The clay content on the average is about 40% and content of clay combined with silt constitutes about 60% in majority of soils. Data on these profiles are given in table 1.

TABLE No. 1

Distribution of manganese in the soil profiles of Jubulpore

Depth (inches)	Colour and Texture	pH	CaCO ₃ %	Clay %	Clay + Silt%	Water- soluble	Exchange- able	Redu- cible	Manganese (in p.p.m.)		
									Active	Total	
Profile I											
0-12	Black and clayey	6.7	0.25	42.6	59.0	0.9	19.4	528.0	548.3	1540.0	0.36
12-24	"	6.7	1.05	37.6	55.2	0.7	14.1	457.6	472.4	1430.0	0.33
24-36	"	6.6	0.96	42.2	57.5	0.9	14.1	616.0	631.0	1485.0	0.43
36-51	"	6.5	0.73	38.5	55.1	3.7	8.8	616.0	626.5	1485.0	0.42
51-77	Brown and clayey	6.8	0.68	22.1	56.0	0.5	18.5	563.2	582.2	1210.0	0.48
Profile II											
0-12	Greyish black, clayey	7.4	2.79	40.9	60.0	0.5	11.3	299.2	311.0	990.0	0.31
12-36	"	7.6	4.37	42.4	47.3	0.4	9.9	246.4	256.7	825.0	0.33
36-60	"	7.6	7.29	41.5	59.2	0.4	6.3	228.8	235.5	715.0	0.33
60-70	Whitish grey, lime concretion	7.8	15.04	32.7	52.3	0.2	6.3	140.8	147.3	715.0	0.21
Profile III											
0-12	Black clayey	7.7	1.15	42.1	60.7	0.5	26.4	211.2	238.1	924.0	0.26
12-36	"	7.8	1.37	46.9	67.7	0.0	15.0	155.0	170.0	704.0	0.24
36-48	Same, lime nodules	7.6	3.95	45.3	68.8	0.7	8.5	132.0	141.2	660.0	0.21
48-60	"	7.7	3.49	46.0	68.2	1.1	7.7	127.6	136.4	704.0	0.19
60-78	Same, white yellow patches	7.8	2.32	45.1	68.0	1.2	3.2	105.6	110.0	484.0	0.23
Profile IV											
0-12	Black, clayey	6.6	0.67	47.2	66.5	0.7	21.1	281.6	303.4	1210.0	0.25
12-24	"	7.3	1.73	46.6	66.8	0.4	23.8	272.8	297.0	990.0	0.30
24-36	"	7.4	2.11	47.4	68.7	1.1	11.4	308.0	320.5	990.0	0.32
36-48	"	7.4	2.59	46.4	67.6	0.5	14.1	272.2	286.6	880.0	0.33
48-60	Greyish black	7.9	3.65	42.7	68.4	0.5	7.0	264.0	271.5	770.0	0.35
60-78	"	8.2	5.01	38.1	64.3	...	2.7	396.0	398.7	880.0	0.45
Profile V											
0-7	Black, clay	6.6	1.44	43.5	64.9	0.7	6.0	457.6	464.3	1320.0	0.35
7-41	"	7.9	1.63	46.2	66.3	0.5	11.3	492.8	504.6	1210.0	0.42
41-51	Black and brown	7.2	2.02	42.2	62.2	0.9	8.5	588.8	598.2	1210.0	0.49
51-74	Reddish brown	6.7	2.59	30.9	51.8	1.4	2.6	717.6	721.6	1155.0	0.63

All the horizons of the profiles are characterised by high content of total and active forms of manganese, but, comparatively lower content of water soluble and exchangeable forms of manganese. The surface soil in the profile I has got the highest content of total manganese (1540 p. p. m.) and then, there is gradual decrease in the content of this constituent downwards. In other profiles also, gradual decrease in the content of total manganese with depth is observed. This supports the previous observation (Biswas, 1953), where it was observed that in black soil profile the usual pattern of distribution of total manganese is either uniform or decrease with depth. The reason or rather the factor responsible for such distribution may be the clayey texture of the soil in all the horizons and absence of leaching due to their being located in an area having low rainfall. Soil reaction in most of the cases is alkaline. These are the conditions which are not at all conducive to the mobilisation of manganese.

Except in profiles I and V, nature of distribution of active manganese follows the same order as that of the total manganese, *i. e.*, slight decrease with depth. In both these profiles, there is accumulation at lower depth. The reaction of most of the horizons in these is on the acidic side whereas in other cases it is on the alkaline side. Low content of calcium carbonate and low pH are mainly responsible for such type of distribution *i. e.*, the factors account for accumulation.

Exchangeable manganese also has highest concentration in the surface and then gradual decrease with depth ; but, accumulation in the sub-soil is found in sub-soil in profiles I and V. The arguments put forward in the case of active manganese may also be applied in these cases also. Surface accumulation of exchangeable manganese was also observed in the previous investigation (Biswas, 1953).

Calcareous soil profiles from Pusa.—Soils of this place are characterised by their high content of calcium carbonate (about 40%) and silty loam texture. These profiles differ markedly from the black soil profiles in the content of both total and active manganese. Content of total manganese varies from 300 to 400 p. p. m. and that of active manganese varies from 17 to 111 p. p. m. The distribution of total manganese is practically uniform whereas that of active manganese is rather irregular. Though the locality is situated in a moderately high rainfall area, action of leaching is balanced or opposed by higher content of calcium carbonate. It was observed previously (Biswas, 1951) that increase in calcium carbonate is associated with decrease in active manganese probably by the shift of the equilibrium, as postulated by Sherman and Harmer (1942) towards the right *i. e.*, formation of inactive oxide of manganese. It is further observed that active manganese is higher in the uncultivated area as compared to the cultivated ones and this is expected though total manganese is practically similar in both cases. Reducible form of manganese which is the potential reserve of available manganese is also small.

Profiles of alluvial soil from Bhadrak, Lucknow.—The soils in most of the horizons have neutral to slightly alkaline reaction, content of calcium carbonate is low. The soils are loamy in texture. The locations from which the profiles were collected represented three areas ; the plots under irrigation, under *barani*, and under grass. One interesting observation is made in the distribution, of total and active manganese in profile I. Both these constituents go on increasing with depth, but at a depth of 17 to 59 inches, there is marked accumulation. It may be mentioned that the location from which the profile was collected was under

TABLE No. 2

Distribution of manganese in the soil profiles of Pusa, Bihar

										Manganese (in p.p.m.)		
Depth (inches)	Colour and Texture	pH	CaCO ₃ %	Clay %	Clay + Silt%	Water- soluble	Exchange- able	Redu- cible	Active	Total	Active	
											Total	
Profile I—(Pentangular field—Saline area)												
0—12	Grey, loam	7.5	32.96	7.9	61.5	0.2	6.3	18.4	24.9	345.0	0.07	
12—17	Grey, yellow streaks	8.2	44.70	26.9	79.5	0.2	4.1	12.9	17.2	402.5	0.04	
17—55	Grey, sandy loam	8.3	46.60	16.6	61.4	0.9	7.7	23.9	32.5	356.5	0.09	
55—66	Grey, sandy	8.4	39.80	28.3	72.0	...	10.3	35.0	45.3	425.5	0.11	
Profile II—(Pentangular field—nonsaline area)												
0—20	Grey loam	7.8	45.22	13.3	68.5	0.2	8.3	22.1	30.6	368.0	0.08	
20—50	Grey, sandy loam	8.0	49.30	7.8	54.3	...	7.8	20.2	28.0	333.5	0.08	
50—56	" "	8.1	36.21	4.4	25.8	0.3	12.4	25.8	38.5	299.0	0.19	
56—61	Grey, loam	10.2	40.67	8.9	62.7	0.6	6.3	29.4	36.3	379.5	0.09	
61—67	Sandy loam, black streaks	8.5	47.10	5.2	46.8	...	14.7	35.8	51.5	310.0	0.17	
Profile III												
0—14	Grey, sandy loam	7.6	28.04	7.9	31.5	0.2	19.3	69.0	88.5	391.0	0.23	
14—28	Grey sandy	7.6	22.53	2.0	9.8	...	14.3	41.4	55.7	322.0	0.17	
28—42	Grey, loam	7.0	28.51	13.8	58.0	0.3	12.0	98.9	111.2	483.0	0.23	
42—70	Whitish grey, sandy loam	7.5	33.71	10.0	56.4	0.1	12.5	78.2	90.8	437.0	0.21	
70—80	Grey clay loam	7.7	33.52	16.5	54.4	...	17.5	82.8	100.3	494.5	0.20	
Profile IV												
0—17	Dark grey, sandy loam	7.4	33.59	6.0	30.8	...	13.8	43.7	57.5	345.0	0.17	
17—35	Grey sandy	7.8	36.08	2.7	17.2	...	12.9	27.6	40.5	322.0	0.13	
35—54	Grey, sandy loam	7.8	35.42	4.3	24.3	...	13.8	25.3	49.1	333.5	0.12	
54—72	Grey, sandy loam	7.9	47.74	9.8	65.0	...	10.1	52.9	63.0	448.5	0.14	

TABLE No. 3

Distribution of Manganese in the soil profiles of Bhadrak Farm, Lucknow

Depth (inches)	Colour and Texture	pH	CaCO ₃ %	Clay %	Clay + Silt %	Water- soluble	Exchange- able	Redu- cible	Manganese (in p.p.m.)		
									Active	Total	Active Total
Profile I (under irrigation)											
0—8	Dark humous colour, loamy	7.8	0.63	15.0	43.0	1.0	32.2	51.5	84.7	368.0	0.23
8—17	Lighter colour, loamy	7.0	Nil	26.0	60.0	...	9.2	138.0	147.2	414.0	0.36
17—59	Same as above	7.7	0.07	30.0	67.0	...	4.1	460.0	464.1	989.0	0.47
59—72	Same, contains black concretions	6.9	0.10	16.0	69.0	...	3.3	193.2	196.5	529.0	0.37
Profile II (under Barani)											
0—6	Dark grey colour	7.0	0.04	19.0	56.0	1.1	35.0	58.9	95.0	391.0	0.24
6—21	Lighter colour	6.8	Nil	21.0	57.0	0.4	16.6	88.3	105.3	368.0	0.29
21—24	„	7.7	0.58	28.0	62.0	...	3.3	69.9	73.2	414.0	0.18
41—56½	Light yellowish brown, sandy	7.6	0.34	15.0	42.0	...	3.3	138.0	141.3	368.0	0.38
Profile III (under Barani)											
0—8	Yellowish grey colour	7.4	0.44	11.0	52.0	1.1	21.2	82.8	105.1	460.0	0.23
8—18½	Whitish grey colour	7.6	0.73	16.0	46.0	0.3	8.8	92.2	101.1	391.0	0.26
18½—49½	More darker	7.5	0.02	33.0	69.0	...	4.1	165.6	169.7	529.0	0.32
49½—56½	Yellowish	7.6	0.15	21.0	54.0	...	3.7	174.8	178.5	552.0	0.32
Profile IV (under grass)											
0—10	Dark humous colour soil	7.9	0.23	18.0	43.0	...	27.6	51.5	79.1	575.0	0.14
10—21	Yellowish brown	7.6	0.54	25.0	47.0	0.9	4.4	239.2	244.5	627.0	0.39
21—40	Same	7.9	2.32	25.0	48.0	0.3	4.1	66.2	70.6	391.0	0.18
40—63	Yellowish colour	7.6	0.73	12.0	25.0	...	3.3	66.2	69.5	345.0	0.20

irrigation. It is well-known that water-logging makes manganese more labile. Naturally, under the influence of irrigation water, a portion of manganese changes into a more labile form (manganous) and travels downwards the profile. Below this zone of accumulation, a zone of accumulation of black *concretions* is observed. This confirms the previous observation that a zone of accumulation of active manganese is often associated with a zone of accumulation of lime concretions below (Leeper, 1946 ; Biswas, 1953). That the irrigation water helps in the soil has also been mentioned by earlier workers.

Accumulation to a certain extent is observed in other profiles also, but is not so well-marked. There is accumulation of active manganese at a depth of 10 to 21 inches in profile IV. Another interesting point to be noted is that there is always surface accumulation of exchangeable manganese. This is well-marked and there is gradual decrease with depth. This is in keeping with earlier observation. The usual form of distribution of total manganese is accumulation at certain depth and then decrease whereas active manganese is observed to have accumulation in two profiles and in other two profiles, the distribution is not regular.

Profiles of semi-arid or desert soil from Delhi.—The profiles are from the cultivated area of the I. A. R. I. farm. The soils have slightly alkaline reaction and sandy texture. There is a decrease in the content of total manganese at certain depth and then increase. The type of distribution of active form is practically uniform throughout the profile and this is expected, from previous experience, to be due to lack of leaching, being situated in a drier region. The ratio of active to total manganese is more or less 0.30 and this is also an indication of lack of movement of labile form of manganese and considerably high level of active manganese as compared to Pusa profiles.

An interesting observation is made if the distribution of total or active manganese in the different horizons of profiles is considered in relation to the content of clay or clay plus silt. Some positive and linear correlation is found between the content of total or active manganese with the content of clay or clay in the horizons of the profiles. In Pusa profiles, correlation between total manganese and clay is positive and the same is the case with clay plus silt. In all the profiles, active manganese increase or decrease with increase or decrease in the clay content and also with clay plus silt, exception being found in two cases only. In the case of profiles from Bhadrak farm, no such correlation is observed except in first two profiles. In the profiles of soil from Delhi, positive correlation is found between content of total manganese and clay or clay plus silt along the depth of the profiles. Active manganese is positively correlated with the content of clay or clay plus silt in the different horizons of the profiles. In profile I of the Jubbulpore group, total or active manganese decreases or increases with the increase or decrease of that of the clay. But in other ones the correlation is not regular.

This may be concluded broadly that both total and active manganese in the horizons of the profiles vary, in general, with the content of clay or clay plus silt. This type of observation was also made by Hoon and Dhawan, (1943).

SUMMARY

Some typical profiles from representative of several group of Indian soils, such as alluvial, black, calcareous and semi-arid, were studied for their distribution of different forms of manganese. Wide variation is observed in the content of manganese in the profiles of different soil groups. The nature of distribution of

TABLE No. 4

Distribution of Manganese in the soil profiles from Delhi

Depth (inches)	Colour and Texture	pH	CaCO ₃ %	Clay %	Clay + Silt %	Water- soluble	Exchange- able	Redu- cible	Manganese (in p.p.m.)		
									Active	Total	
Profile I											
0—12	Light brown, sandy loam	8.2	0.32	19.5	40.3	...	3.3	174.8	178.1	552.0	0.32
12—24	Yellowish brown, sandy	7.9	0.56	14.0	25.3	0.2	8.5	138.0	146.7	460.0	0.32
24—36	Loam	7.9	0.30	16.5	33.0	0.2	13.8	156.4	170.4	506.0	0.34
36—48	Same as above	7.9	0.31	18.7	35.2	0.4	9.6	165.6	175.6	506.0	0.35
Profile II											
0—6	Light brown, sandy	8.2	0.68	16.0	33.7	...	19.5	138.0	157.3	483.0	0.38
6—14	Yellowish brown, sandy	8.3	0.53	14.5	27.2	0.6	6.3	147.2	154.1	460.0	0.34
14—41	Loam to clay loam	8.2	0.34	10.5	21.1	0.5	5.2	110.4	116.1	368.0	0.32
41—51	Same as above	7.9	0.40	17.1	35.5	...	2.9	193.2	196.1	529.0	0.37
Profile III											
0—9	Light brown, sandy loam	8.3	0.42	22.3	46.1	...	15.6	193.2	208.8	621.0	0.34
9—13	Yellowish brown, sandy	8.2	0.58	18.9	37.1	...	9.7	184.7	193.7	529.0	0.37
13—17	Yellowish brown loam	8.3	0.36	22.6	49.4	0.2	10.1	230.0	240.3	598.0	0.40
17—40	Light brown sandy loam	8.2	0.34	14.7	32.5	...	6.9	147.2	154.1	460.0	0.34
40—50	Darker than above	8.4	0.52	17.6	39.7	...	6.4	193.2	199.6	529.0	0.38
Profile IV											
0—6	Light brown, sandy	8.4	0.48	15.4	33.5	...	9.7	128.8	138.5	506.0	0.27
6—36	Yellowish brown, sandy	8.4	0.12	11.3	21.6	...	5.1	101.2	106.3	368.0	0.29
36—below	Light loam	8.3	0.16	12.8	25.5	...	3.7	138.0	141.7	391.0	0.36

total and active manganese is found to be influenced by the action of leaching and to vary directly with the content of clay or clay plus silt in the different horizons of the profiles. Available manganese is found to be influenced by soil reaction and content of calcium carbonate. Exchangeable manganese has surface accumulation and then decrease with depth.

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USE OF MICRONUTRIENTS AS FERTILIZERS

By

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The recent discoveries about the importance of small amounts of copper, zinc, boron and manganese in the physiology of higher plants have added interest to the studies on the role of these elements in a number of soil plant problems. These elements or micronutrients are now recognized to be essential plant nutrients and a shortage of one or more of these is known to adversely affect the metabolism and growth of plants. Severe insufficiency of a micronutrient in the soil often gives rise to a disease of plants grown in it showing symptoms which are typical of the particular deficiency. However, where several deficiencies exist together the symptoms may be complicated, and therefore difficult to distinguish them as those of any known deficiency of a particular trace element. Further it has been noted by previous investigations that sometimes, plants suffering from a deficiency of micronutrients may not show any symptoms of the deficiency at all, except that their growth is stunted or that they display the symptoms only for a short period in the growing season. It has also been observed that on many soils plants suffer from a deficiency of a number of micronutrients simultaneously, though they may only show symptoms of one or even of none of them. Micronutrient deficiencies are also often known to occur in soils which contain adequate quantities of the micronutrient, but in a form unavailable to the plant. It may, therefore, be realised that the deficiency or requirements of soils for the different micronutrients for a normal and vigorous growth of plant cannot be easily determined. In these circumstances empirical trials wherein these elements are used as supplementary fertilizers will help a great deal in knowing the micronutrients requirement of soils. Such experiments in foreign countries with micronutrient fertilizers have shown that large acreages of cultivated land in different parts of Europe, Australia, U.S.A. are deficient in one or the other of micronutrient. So far as we know, there has not been any definite knowledge of the deficiency of micronutrients in large tracts of the cultivated soils of India. Daji¹ observed that the cause of the "band" disease of areca palm is manganese toxicity. We² have, however, shown that application of copper sulphate or zinc sulphate separately to the soil, leads to an improvement and cure of the diseased areca palms. Basu and Rege³ have analysed the highly eroded soils of the Bombay State for their content of B, Zn and Mn and have studied the responses of crops to the application of these micronutrients to the soil. In conclusion these authors have observed that "in the scarcity zones of the Bombay State, advantage of increasing the food crops by the application of secondary elements (or micronutrients), can be easily taken up."

The present paper gives data of our pot culture experiments and field trials wherein we have used copper, zinc and boron as fertilizers in some poor soils of the Maharashtra and Konkan regions of the Bombay State.

EXPERIMENTAL AND DISCUSSION OF RESULTS

In the pot culture experiment, a large quantity of soil from the surface 9" layer from the poor crop yielding field was collected. The different treatments given to the soil filled in pots were (1) control, (2) copper, (3) organic manure, (4) copper plus phosphate manure, (5) phosphate and (6) copper plus organic manure.

Copper was supplied at the rate of 5 milligrams Cu, per hundred grams of air-dry soil. The copper salt used in the present experiment was cupric oxide (CuO). Organic manure was added in the form of oil-free groundnut cake, on the basis of 15 milligrams nitrogen per hundred grams air-dry soil. Calcium monophosphate was used at the rate of 30 milligrams P_2O_5 per hundred grams air-dry soil.

The results of crop yields obtained with the different treatments are given in the table 1.

TABLE No. 1

Yield of wheat plants in grams per pot with different treatments of soil

Pot No.	Treatment					
	Control (gms)	Cu (gms)	Org. M (gms)	P (gms)	P+Cu (gms)	O.M+Cu (gms)
1	8.35	8.18	7.88	12.48	8.30	15.84
2	5.57	8.65	7.75	10.61	8.48	13.70
3	4.20	7.85	7.60	11.31	10.36	13.30
4	6.75	9.13	7.45	10.45	90.80	11.50
Total	24.87	33.81	30.68	44.85	36.22	54.34
% Increase of crop over control		35.8	23.30	80.00	45.60	118.34

It is seen from figures of crop yields with different treatments that copper alone has given an increase of 35.8 % over the control; phosphate treatment has given 80 % increase but the addition of organic manure alone has resulted in an increase of only 23.3 % over the control. The yield of crop with the treatment (O.M+Cu) is the highest among the yields obtained with the different treatments of the soil and it is 118.3 % more than the yield from the control or untreated pots.

The data of yields were statistically analysed. "F" for treatment variance was found to be significant at zero percent level.

The sum of squares for "between treatments" was further split into components for detecting the significance of response to the different main factors and their interaction. In the table 2 responses have been so tested for their significance.

TABLE 2

Analysis of variance for main responses and interactions

Source of variation	D.F.	S.S.	M.S.	F
Main response to O.M.	1	43.3622	43.3622	31.16**
„ „ „ Cu	1	35.7305	35.7305	25.67**
„ „ „ P	1	31.3320	31.3320	22.57**
Interaction of P and Cu	1	19.2941	19.2941	13.86**
„ „ „ O.M. and Cu	1	13.5424	13.5424	9.73**
Within treatments	18	25.0513	1.3917	...

The results of statistical analysis clearly show that the main responses to all the three factors organic matter, copper and phosphate are highly significant. Similarly it can be seen that the interaction between copper and organic manure is highly significant indicating thereby that the combined effect of copper and organic manure added together to the soil is greater than the sum of the effects on the yield of crop obtained by the separate addition to the soil of each of these two fertilizers, copper and organic manure. A highly significant interaction is also evident when copper and phosphate are added together to the soil, but in this case the application of the two manures together is not found to be favourable for the crop yield. Copper appears to partially counteract the beneficial effect of phosphate addition on the crop resulting in a lesser yield of crop with the simultaneous addition of copper and phosphate than what is obtained with the addition of phosphate alone.

In the field experiments carried out under our supervision in some cultivators' fields, copper sulphate was used as a supplementary fertilizer for paddy crop. Following results were obtained :—

TABLE 3

Yield of paddy grain in Bengali maunds per acre

Place	District	Treatment of seed-bed	Control	Yield in maunds Copper sulphate	increase %
Alibag	Kolaba	Rabbed	19.75	27.0	36.7
Murdi	Ratnagiri	Rabbed	12.00	22.0	83.3
Palghar	Thana	Manured with cake and super-phosphate	20.80	31.6	52.0

In another pot culture experiment of a factorial design, we tried the application of the following different trace elements for the soil filled in pots. The treatments were as follows :—

- (1) Control, no treatment,
- (2) Organic manure,
- (3) Boric acid,
- (4) Zinc sulphate,
- (5) Organic manure plus boric acid,
- (6) Organic manure plus zinc sulphate,
- (7) Boric acid plus zinc sulphate and
- (8) Organic manure plus boric acid plus zinc sulphate.

Wheat was grown in pots. The dose of the micronutrients added to the soil in pots was 5 mgm, of the element per 100 gms air-dry soil. Oil free groundnut cake was used as the organic manure on the basis of 15 mgm per 100 gms soil. The results of crop yields are given in the table below :—

TABLE 4
Yield of wheat plants (grain straw) in pots receiving
different treatments

Pot No.	Treatments							
	Control	Org. M	B	Zn	Org. M + B	B + Zn	Org. M + Zn	Org. M + B + Zn
1.	6.5	9.7	8.3	7.7	11.3	6.0	10.1	11.5
2.	7.0	10.3	9.6	8.7	14.7	6.7	13.5	13.0
3.	7.3	9.3	8.8	7.9	12.0	5.7	11.0	12.3
4.	7.7	10.5	8.4	8.0	14.1	6.2	12.3	11.2
5.	7.5	8.7	8.5	6.8	13.3	5.9	11.2	10.5
6.	7.9	8.6	8.3	6.0	10.6	5.2	10.5	9.4
Total	43.9	57.3	51.9	45.1	76.0	35.7	68.6	67.9
Grain	27.4	38.0	33.0	28.1	53.2	22.5	46.8	43.1
Straw	16.5	19.3	18.9	17.0	22.8	13.2	21.8	24.8
% increase over control		32.0	18.0	2.7	73.0	19.0	56.0	54.0

It may be observed from the results in the table given above, that the increase in crop due to the addition of zinc salt, alone to the soil was only 2.7 % while that due to boric acid alone was 18 %. The increase due to the addition of organic manure was 32 % over the control. The combination of zinc salt and organic manure gave an increase of nearly 56 % over the control, while boric acid and organic manure when added together gave an increase of 73 %. The combination of zinc sulphate and boric acid, however, decreased the yield by about 19 % below the control.

Statistical analysis of the data showed that "F" for treatment variance is significant at one per cent level. Analysis of variance for significance of main responses of individual factors and their interactions, revealed that the main response due to organic manure is highly significant while the main responses due to boron and the three interactions between (1) organic manure and zinc, (2) organic manure and boron, and (3) zinc and boron; are all statistically significant.

SUMMARY AND CONCLUSION

(1) Application of copper salt alone or in combination with organic manure to the soils in Maharashtra and Konkan regions of the Bombay State gives a significantly large increase in the crop, from the soils studied by us.

(2) Application of boric acid alone gives a significant increase in crop.

(3) Addition of zinc sulphate alone to the soils in Maharashtra and Konkan regions is not found to be beneficial.

(4) Application of micronutrients copper, zinc or boron in the form of their salts to the soil singly, without the addition of organic manure is not so much beneficial for crop as the simultaneous addition of the micronutrient and the organic manure.

(5) The two factor interactions between micronutrient as one part and organic manure as the other, are found to be statistically significant.

(6) The main effects of the micronutrients Cu and boron singly are found to be significant while that of zinc singly is not significant.

(7) From these results it may be safely concluded that micronutrients should be generally applied along with organic manures.

(8) Combinations of two micronutrients Zn and B is found to be harmful for plants, so also simultaneous addition of copper salt and phosphate.

(9) These results indicate that before combining the nutrients into a fertilizer mixture for application to any soil, the different possibilities about the nature of interactions between the constituents requires to be thoroughly investigated.

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EFFECT OF TRACE ELEMENTS ON NITROGEN FIXATION

By

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Of late it has been suggested that besides curing deficiency diseases, manuring by small amounts of trace elements increases crop yield. Babier and Chabannes¹ have been able to show that tomatoes in culture solution show increased vegetative growth at boron levels beyond those necessary to prevent deficiency symptoms. Similarly substantial increase in dry bean yields were obtained recently by fertilizing with zinc sulphate, even when zinc deficiency symptoms were not apparent on unfertilized plants.²

Their exact role in increasing crop production is not very well understood. The fact that they are effective in small amounts has led many scientist to believe that micronutrients act as catalysts, but their functions are not known. Briggs³ has suggested that boron is necessary for the proper utilisation of nitrogen by plants and that nitrogen absorption decreases with increasing boron deficiency. Boron, molybdenum and vanadium are considered essential for the development of legume nodules⁴⁻⁶. It appears that these trace-elements may be connected with the nitrogen economy of soils. So the present studies were undertaken to find out their effect on nitrogen fixation obtained by adding lucerne to soils. Their effects on carbon transformations and Azotobacter population have also been studied.

EXPERIMENTAL

Two hundred grams of soil were taken in shallow enamelled dishes of 9" diameter. The soil was previously well powdered and passed through a 80 mesh sieve. 0.5% carbon in the form of well powdered, air dried, whole lucerne plant was added. Molybdenum, vanadium, boron and zinc were added in doses of 0.005% and 0.01% as sodium molybdate, vanadium pentoxide, borax and zinc chloride respectively. These dishes were exposed to the light of a 500 watt electric bulb, kept at a distance of two feet from the dishes. Another similar set, covered with a thick black cloth was kept besides the exposed dishes. The moisture was kept at 20% throughout. The material in the dishes was stirred with a glass rod on alternate days to help aeration and oxidation. Two samples were taken out, one after three months and the other after six months. They were oven-dried and analysed for total carbon and total nitrogen. Total carbon was estimated by Robinson, Maclean and William's method⁷ and total nitrogen by salicylic acid reduction method.⁸ Azotobacter colonies were grown on Beijerinck's medium :—

Chemical analysis of the soil used in these experiments.

	%		%
Carbon	= 0.4021	Magnesium oxide	= 1.1420
Nitrogen	= 0.0398	Calcium oxide	= 0.9834
Loss on ignition	= 3.4	Potassium oxide	= 0.7496
HCl insoluble	= 80.2	Phosphoric acid	= 0.0745
Sesquioxides	= 11.2	1 % citric acid	= 0.0293
Iron oxides	= 4.3	soluble phosphate	
		Total carbonates	= 1.24
		pH (1:25 soil water ratio)	= 7.6

Chemical analysis of lucerne plant .

Carbon	= 42.06	Calcium oxide	= 1.6800
Nitrogen	= 2.09	Total P_2O_5	= 0.4132
Sesquioxides	= 0.30	Potassium oxides	= 3.4200
Moisture	= 10.60	C:N ratio	= 20.12
Ash	= 10.45		

TABLE I (a) Exposed

200 gms of soil + 0.5 % Carbon as lucerne + 0.005 % Mo

Time of exposure in days	Total carbon %	Total nitrogen %	Carbon oxidized %	Increase in nitrogen %	Efficiency	Azotobacte millions per gm
0	0.9011	0.0640	---	---	---	2.0
90	0.7162	0.0733	0.1849	0.0093	50.2	---
180	0.6530	0.0757	0.2481	0.0117	47.1	9.1

TABLE I (b) Covered

0	0.9013	0.0642	---	---	---	2.0
90	0.7384	0.0686	0.1629	0.0044	27.0	---
180	0.6945	0.0694	0.2063	0.0052	25.1	1.2

200 gms of soil + 0.5% Carbon as lucerne + 0.01 % Mo

TABLE II (a) Exposed

0	0.9024	0.0645	---	---	---	2.0
90	0.7109	0.0743	0.1915	0.0093	51.6	---
180	0.6482	0.0772	0.2542	0.0127	49.9	9.1

TABLE II (b) Covered

0	0.9002	0.0635	---	---	---	2.0
90	0.7320	0.0687	0.1682	0.0052	30.9	---
180	0.6884	0.0698	0.2118	0.0063	29.7	14.1

200 gms of of soil + 0.5% Carbon as lucerne + 0.005 % V

TABLE III (a) Exposed

0	0.9000	0.0631	---	---	---	2.0
90	0.7199	0.0714	0.1801	0.0083	46.0	---
180	0.6568	0.0740	0.2432	0.0109	44.8	8.8

TABLE III (b) Covered

0	0.9006	0.0638	---	---	---	2.0
90	0.7405	0.0680	0.1601	0.0042	26.2	---
180	0.6982	0.0688	0.2024	0.0050	24.7	12.1

200 gms of soil + 0.5% Carbon as lucerne + 0.01 % V

TABLE IV (a) Exposed

0	0.9009	0.0637	---	---	---	2.0
90	0.7138	0.0728	0.1871	0.0091	48.6	---
180	0.6512	0.0754	0.2497	0.0117	46.8	9.2

TABLE IV (b) Covered
200 gms of soil + 0.5% Carbon as lucerne + 0.01% V

Time of exposure in days	Total carbon %	Total nitrogen %	Carbon oxidized %	Increase in nitrogen %	Efficiency	Azotobacter in millions per gm
0	0.9014	0.0642	...	...	...	2.0
90	0.7345	0.0687	0.1669	0.0045	26.90	...
180	0.6902	0.0695	0.2112	0.0053	25.09	1.3

200 gms of soil + 0.5% Carbon as lucerne + 0.005% B

TABLE V (a) Exposed

0	0.9025	0.0647	...	...	...	2.0
90	0.7218	0.0728	0.1807	0.0081	44.8	...
180	0.6571	0.0752	0.2454	0.0105	42.7	4.9

TABLE V (b) Covered

0	0.9028	0.0648	...	...	...	2.0
90	0.7645	0.0681	0.1383	0.0033	23.8	...
180	0.7111	0.0691	0.1917	0.0043	22.4	7.8

200 gms of soil + 0.5% Carbon as lucerne + 0.01% V

TABLE VI (a) Exposed

0	0.9030	0.0649	...	...	...	2.0
90	0.7212	0.0733	0.1818	0.0084	46.2	...
180	0.6568	0.0759	0.2462	0.0110	44.6	5.0

TABLE VI (b) Covered

0	0.9036	0.0650	...	...	...	2.0
90	0.7630	0.0686	0.1406	0.0036	25.6	...
180	0.7098	0.0697	0.1938	0.0047	24.2	7.8

200 gms of soil + 0.5% Carbon as lucerne + 0.005% Zn

TABLE VII (a) Exposed

0	0.9016	0.0644	...	...	...	2.0
90	0.7222	0.0724	0.1794	0.0080	44.5	...
180	0.6582	0.0749	0.2434	0.0105	43.1	4.8

TABLE VII (b) Covered

0	0.9013	0.0643	...	...	...	2.0
90	0.7658	0.0675	0.1355	0.0032	23.60	...
180	0.7112	0.0685	0.1901	0.0042	22.09	7.6

200 gms of soil + 0.5% Carbon as lucerne + 0.01% Zn

TABLE VIII (a) Exposed

0	0.9027	0.0646	...	...	...	2.0
90	0.7216	0.0728	0.1811	0.0082	45.2	...
180	0.6577	0.0755	0.2450	0.0109	44.4	4.8

TABLE VIII (b) Covered

0	0.9019	0.0645	...	...	...	2.0
90	0.7639	0.0678	0.1380	0.0033	23.9	...
180	0.7102	0.0685	0.1917	0.0040	20.8	7.9

TABLE IX (a) Exposed
200 gms of soil + 0.5% Carbon as lucerne

Time of exposure in days	Total carbon %	Total nitrogen %	Carbon oxidized %	Increase in nitrogen %	Efficiency in millions per gm	Azotobacter
0	0.9011	0.0643	...	...	...	2.0
90	0.7238	0.0718	0.1773	0.0075	42.3	...
180	0.6584	0.0743	0.2427	0.0100	41.2	4.5

TABLE IX(b) Covered						
0	0.9015	0.0644	...	...	...	2.0
90	0.7680	0.0673	0.1335	0.0029	21.7	...
180	0.7125	0.0682	0.1890	0.0038	20.1	7.6

DISCUSSION

From a careful perusal of the foregoing results it appears that molybdenum, vanadium, boron and zinc when used in conjunction with organic matter like lucerne plant, help in the oxidation of organic matter added. With molybdenum and vanadium, there is appreciable increase in the oxidation, both in light and in dark, while boron and zinc increase the oxidation only to a slight extent. In this respect boron is little superior to zinc—the order of increase in the oxidation is $\text{Mo} > \text{V} > \text{B} > \text{Zn}$. Higher dose of these trace-elements causes greater oxidation of the added organic matter, but the difference in the oxidation induced by the two doses is slight. There is always greater oxidation in light than in dark. It will be interesting to record in this connection that Dhar and Palit⁹ also found increased oxidation of carbohydrates in presence of copper and iron compounds.

The addition of these trace-elements also brings about an increase in the efficiency of nitrogen fixation. Molybdenum helps considerably in nitrogen fixation and vanadium comes next. The order of increase in efficiency of nitrogen fixation is same as that of increase in oxidation. Increasing the dose of the trace-element added, has little effect on nitrogen fixation. This supports the earlier observation made by various scientists that these trace-elements are needed only in very small amounts. Invariably there is greater fixation in light than in dark.

Of all the four trace-elements studied, molybdenum appears to be more intimately connected with nitrogen content of the soil. Menlen¹⁰ drew attention to the fact that in general, productive soils are found to have higher content of molybdenum than soils of low capacity for crop production. Leeper¹¹ regards molybdenum to be essential for nitrogen fixation both by *Azotobacter* and *Rhizobia*. Anderson and Spencer¹² have observed that molybdenum increases both yield and nitrogen percentage in the case of subterranean clover. Datta and Gurubasava¹³ recorded increased yield of berseem with the application of molybdenum and boron. Sorteberg¹⁴ obtained an increase in the yields of lettuce plants when ammonium molybdate was applied as a fertilizer. Similarly boron is also believed to increase nitrogen fixation by *Azotobacter chroocum*. Dastur and Singh¹⁵ got increased cotton yields by the application of zinc and boron. Zinc increases the yields of wheat, maize, oats, lupin and pea.¹⁶

These observations together with the author's results suggest that these elements stimulate nitrogen fixation. Their exact role is not very well understood. They are generally believed to act as catalysts and reaction regulators and as such might be accelerating the nitrogen fixing process.

These trace-elements have also been found to stimulate the growth of Azotobacter by the authors. In dark, with the addition of molybdenum, there is considerable increase in the number of Azotobacter population. Vanadium also appreciably helps Azotobacter growth. Their number is always greater in dark than in light. Boron and zinc increase the growth of Azotobacter to a slight extent only. Lipman and Burgess¹⁷ have also recorded the stimulating effect of zinc on the nitrifying flora of a soil.

Furthermore it may be concluded that these four trace-elements are not at all toxic to the Azotobacter population up to a dose of 0.01% in the soil studied by us. On the other hand, they exert a beneficial effect on its growth when applied in the above dose.

The study of the authors has clearly shown that trace-elements like molybdenum, vanadium, boron and zinc not only cure deficiency diseases as has been observed by others, but also help in fixing atmospheric nitrogen by adding organic matter to soil. Their use in conjunction with organic matter offers one more cheap method of improving the nitrogen content of our nitrogen deficient soils.

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SECTION—7
ACID, ALKALI AND SALINE SOIL
RECLAMATION OF ALKALINE LANDS IN THE CAUVERY
METTUR PROJECT AREA

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INTRODUCTION

The Cauvery Mettur Project area comprises the Taluks of Patukkottai, Mannaragudi in the district of Tanjore. Vast areas of saline and alkaline lands exist in this area. They may be easily recognised by the stunted or patchy growth of crops or in severe cases by the complete absence of vegetation. In the summer months white patches of chlorides and sulphates of sodium and in worst places black patches due to the presence of sodium carbonate are common sights in these areas. Under the ordinary cultivation practices the yield of paddy is under 500 lbs per acre and in places with the black alkali the crop cannot be established. The actual extent of such lands is not known, but it may be assumed to be as high as 50,000 acres. The importance of such lands being brought to profitable cultivation in these days when the rice supply position is short of demand can hardly be over emphasised. With a view therefore, to find out a suitable and economical method for the large scale reclamation of these soils an experiment was laid out at an ideal centre in Seethambalpuram village near Pattukkottai in 1949.

Occurrence of the alkaline lands.—The Cauvery Mettur Project area is of a gently rolling topography. The rise and fall of the landscape is imperceptible in general and tend to cause stagnation of water in low lying areas resulting in salt concentration. The water table has risen to within 3'—5' from the surface after the introduction of irrigation. Surface drainage is poor and water logging occurs in the rainy months. Saline and alkaline lands occur in low lying areas and in many pockets of depressions. The most important cause for the formation of alkaline lands in this area is therefore is the lack of proper drainage facilities and the consequent rise of the ground water level.

Materials and methods.—The reclamation trials were conducted in Seethambalpuram village near Pattukkottai. The site chosen was devoid of any vegetation. The pH of the soil was above 8.5 and the total soluble salts for the top foot samples did not exceed 0.1%. All the essential plant food materials (NKP) in the available form were negligibly small and there was a high degree of saturation

of the clay complex with soda. These were evidently responsible for the lack of crop growth in the area. The analysis of irrigation water collected both from the canal as well as from the tank which is filled first and then used for irrigation, revealed that they are alkaline with a pH above 8.5. It would appear therefore, that any reclamation method of these soils should achieve not only the correction of soil and water alkalinity but also a consistent and efficient nutrition status in the soil for its profitable exploitation. With these objects in view an experiment was laid out and carried over for three cropping seasons (1950, 1951 and 1952).

EXPERIMENTAL DESIGN

The amendments selected to study their comparative merits to achieve the objects cited above are :—

- (1) Gypsum in 2 dozes — $2\frac{1}{2}$ and 5 tons per acre.
- (2) Green leaf in 3 dozes — 2,500, 5,000 and 7,500 lbs per acre.
- (3) Lime in 1 doze — 1 ton per acre.
- (4) Molasses in 2 dozes — $2\frac{1}{2}$ and 5 tons per acre.

Twenty treatments were formed including a control in such a way that the effect of the various soil correctives alone and in combinations that are important, could be studied. The treatments are :—

- (1) Control (local practice — maximum washing)
- (2) Gypsum $2\frac{1}{2}$ tons per acre
- (3) 2 plus 2500 tons green leaf per acre
- (4) 2 plus 5000 „
- (5) 2 plus 7500 „
- (6) Gypsum 5 tons per acre
- (7) 6 plus 2500 tons green leaf per acre
- (8) 6 plus 5000 „
- (9) 6 plus 7500 „
- (10) 2500 tons green leaf per acre
- (11) 5000 „
- (12) 7500 „
- (13) 10 plus 1 ton lime per acre
- (14) 11 plus „
- (15) 12 plus „
- (16) 1 ton lime per acre
- (17) Molasses $2\frac{1}{2}$ tons per acre
- (18) „ 5 „
- (19) 17 plus 1 ton lime per acre
- (20) 18 plus „ „

The design adopted was the randomised block design. Four complete and compact blocks differing in level and alkalinity with long and narrow plots

similar to each other. Within a block have selected and cross and main trenches for drainage were provided for. The 20 treatments were allotted at random within a block and after the application of chemicals 10 to 12 washings (flooding and draining) were given to all plots. Then a uniform application of green manure at 5000 lb per acre 15 days before and ammonium sulphate at 30 lb per acre one month after transplanting were given to each plot including the control. The control which is the local practice consists of mere washing followed by the usual ryots' method of cultivation. During the second and third years the plots were only cultivated following the usual cultivation practices. The Samba crop with Co 25 paddy variety was raised all the 3 years.

ANALYSIS

The grain and straw yields of paddy for each year were statistically analysed and at the end of three years they were combined in a three way table and the main effects of the various ameliorants were tested. The difference between the first year's and the third year's yield was also worked out, which with the proper sign represents a measure of the residual effect produced by the various treatments at the end of three years. These figures were also subjected to statistical analysis with a view to pick out those treatments that have produced the maximum residual effect and that have corrected the soil alkalinity and maintained significantly increasing yields.

After the harvest every year, first foot soil samples were collected from each plot and analysed for pH, total solids, degree of alkalization, organic matter, etc.

DISCUSSION

The problem of salinity and alkalinity has been studied in detail by Kelly and his colleagues,³ who have emphasised the value of gypsum treatment and flooding. For the removal of exchangeable sodium compounds toxic to plants different materials have been applied to soils in America with satisfactory results. The application of gypsum brings about the conversion of sodium carbonate into sodium sulphate and sodium exchange compounds into calcium compounds. Sulphur application to soils of good lime status activates the water soluble calcium compounds. The oxidation product of sulphur (sulphuric acid) reacts with the soluble carbonates and sodium exchange compounds, iron sulphate and aluminium are acidic in reaction as a result of the hydrolysis when applied to the soil and the reactions brought about are fundamentally similar to that of sulphur. Molasses as a soil corrective has also been applied for the reclamation of alkaline lands. The unrecoverable sugars that it contains undergo decomposition and the organic acids produced combine with the sodium carbonate and bicarbonate present in the soil and neutralise them. In the presence of calcium carbonate in soil, the organic acids combined with it and the calcium so mobilised displaces the sodium that has entered the clay. According to Dhar and his collaborators molasses is a better reclaiming agent for alkaline land than either gypsum or sulphur as there is nitrogen loss from soils when these latter agents are applied to alkaline soils while molasses adds nitrogen. The reclaiming effect is much quicker than that of gypsum or sulphur because the acids formed from molasses neutralise the alkali quickly.

Reclamation of alkaline lands on a field scale with the application of gypsum and sulphur was done by the Chemistry section of the Agricultural College and

Research Institute, Coimbatore in the Kattalai High level channel area, Trinelveli district. The improvement in the permeability of the soils and the reduction in pH was remarkable. The yield obtained during the first year was 1000 lb per acre and in the second year after the incorporation of a green manure crop was 3000 lb per acre in the gypsum treated plots and was even higher than what was obtained from fertile fields in the vicinity. In this area as well as in other parts of the presidency alkaline lands have been reclaimed by the application of liberal doses of bulky organics, flooding and draining but this process is a prolonged one.

As has already been stressed before the soils of the C.M.P. area are "hungry" in addition to other limiting factors. The soil correctives were therefore chosen and the various treatments formed to try their comparative effects in remedying all the defects, in the soil irrigation water consistent with their cost and availability. Green manure in the 3 levels will not only act as soil corrective but also build up soil fertility and the proper physical condition. Gypsum, lime and molasses are available from the adjoining districts. As the lime status of the top soil in these areas is poor, sulphur has been omitted and liming alone and in combination with the green manure and molasses are included in the treatments. One treatment has no chemical ameliorant and reveals the effects of mere washing. All the different treatments have brought down the pH of the soil from the original pH of 9 to between 7 and 8.5. The total solids and chlorides in these soils were even in the original samples far below the limit considered excessive and the treatments have not induced any salt accumulation. The water soluble carbonate has been practically removed from the soil by almost all treatments effectively. The lower pH figures for the different treatments also indicate the effectiveness of the different ameliorants, for successful reclamation of these soils. The base exchange capacity of the surface foot of soil has increased in all cases as judged from the samples collected after the second year from the original low values of the order of 3 to 8 to 5 to 13 M. E. with the result of a corresponding decrease in the degree of alkalization. The essential plant nutrients would appear to have been added mainly by treatments involving green leaf and molasses.

Statistical analysis of the field data for all the three years, have shown that the treatments have produced different effects. The addition of chemicals like gypsum and lime as amendments in the first year have not produced any significantly better residual effect at the end of three years than the local practice which consists in mere washing followed by using 5000 lb green leaf as basal dressing and 30 lb N of ammonium sulphate as top dressing. Green matter alone in the first year at a rate of 2500 lb to 5000 lb as an amendment and then cultivated as usual in the first and subsequent years has yielded steadily increasing grain and straw yields. The response curve bends quadratic sum of squares is significant in the case of straw and the residual effect at 7500 lb level. The leaf level beyond 5000 lb per acre would therefore, appear to depress the yield of straw. The green matter at 5000 lb per acre not only corrects alkalinity but also exhibits proper residual effects with the yield remaining a linear function with or without the use of chemicals. The use of chemicals therefore, appears to be unnecessary to put the soil into profitable cultivation.

Although the use of molasses produced maximum yield in the first year the residual effect was low as seen from the decreasing yields in subsequent years. Hence it is to be used every year in such soils to get good returns which of course depend on its availability and cost.

SUMMARY

- (1) The importance of the problem of alkaline land reclamation in the Cauvery Mettur Project area is stressed.
- (2) An incscription of the field experiment at Seethambalpuram, Pattukkottai Taluk with the justification for the choice of different soil correctives is given.
- (3) A practical method of reclaiming the vast alkaline lands of the Cauvery Mettur Project area is recommended.

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SALINE AND ALKALI SOILS OF INDIA

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Saline and alkali soil conditions reduce the value and productivity of considerable area of land in India. These soils are regarded as a class of problem soils which can be found in almost all normal (zonal) soils as encroaching spot in relation to certain elements of topography. The introduction of irrigation through canal system in the arid and semi-arid regions, *e.g.*, the Punjab, U. P. and Bombay-Deccan brought about an increase in unproductive areas amounting to several thousand square miles due to accumulation of salts in the surface soil. The occurrence of these soils is quite large irrespective of meteorological influence and the principal areas affected are (1) throughout the Indus valley, (2) valleys and basins of western India, (3) the Ganges valley west of about 80° E long., (4) the uplands of the Deccan Plateau especially between the Tapi, Godavari and Bhima rivers, (5) the saline marshes of the sea coast and of the deltas of the Ganges, Cauvery and Mahanadi and (6) the coastal salt flats along the Rann of Cutch.

The problem is an old one, which drew governmental attention as early as 1876 when a Commission known as "*Reh* Commission" was set up to investigate into the causes of the deterioration of the soils of the U. P. which had previously been fertile. Leather (1897) initiated scientific investigations on the problem, based on the informations submitted in the report of the Commission, and found that the injurious salts limiting crop growth and reducing the value of land were the decomposition products of igneous rocks under natural weathering process and were present in the soil profile itself which became evident on the surface layers under certain predisposing conditions like, (1) arid and semi-arid climate, (2) an impervious sub-soil or hard pan or (3) temporary abundance of humidity in the soil interspersed with dry period. He tried to assess the extent of distribution of such unproductive (saline and alkali) soils in the Punjab, U. P., Gujrat and Bombay-Deccan and included them under the common term *usar*. The "*Usar*" Reclamation Committee of the U. P. reviewed the technical work done on such soils and reported (1940) that alkaline conditions were mainly due to the presence of sodium carbonate and bicarbonate (to the extent of 0.1 to 0.4%) the exact quantity of which in the soil profile differed according to the nature of the soil and sub-soil such as *kankar* (CaCO_3 concretions) beds and high water table. The alkaline layer was found to extend on average to a depth of 3–4'. The extent of distribution of saline soils in the province was also not negligible and these were characterised by presence of sodium chloride and sulphate, very little sodium carbonate or bicarbonate and "open" texture and state of flocculation. The alkali soils of the province which showed strongly alkaline reaction were classed according to

the Russian system of pedological nomenclature as "Solonetz" and the saline soils as "Solonchaks."

Studies on degenerated soils of the U. P. under a scheme on soil survey and soil work of the State Government have made considerable progress during the last few years (Agarwal and Mehrotra, 1952). The *usar* soils are usually distributed in the low-lying and ill-drained areas of the State, for example in the district of Aligarh. All the factors which together contribute to soil salinisation and alkalinisation, e.g., arid climate, poor drainage and alkaline nature of high ground waters are co-existent. In the district of Kanpur, besides a tract similar to the Aligarh condition, there is another tract of *usar* land with a level topography which has been rendered unculturable due to impeded drainage as a result of hard clay pan in the sub-soil. Morphological studies of *usar* soil profiles reveal formation of hard solonetz like structure at the top. For salinity appraisals, laboratory examination of profile soil samples from a large number of *usar* tract of the State had been made under the scheme. The salinity (alkali) status of a typical *usar* soil profile has been given in Table I (Agarwal and Mehrotra, 1952).

Some of the *usar* soils as revealed by analysis (Table I) are found to have attained nearly the last stage of degradation, the exchange complex of the soil at the surface or at some depth below having been fully saturated with sodium. The pH value and salt content are highest at the top decreasing with depth. The other soils show high alkali status (pH 10.5—8.2) and have high contents of soluble salts (4.4—0.2 %) at the top. This shows that there has been no downward movement of water and the upward rise had been quite rapid. From textural point of view, the alkali soils at the first and second horizons are found to be impervious and the profiles of these soils are generally associated with *kankar* or definitely hard pan restricting the upward movement or downward flow of water. Utilization of such soil for agricultural purposes is extremely problematic. There are other milder types which are expected to respond quickly to the corrective methods of reclamation. Development of planned system of drainage is considered prerequisite of all reclamation projects. The suggested methods of reclamation of *usar* soils are, (1) mechanical—heavy application of water to wash out salts, (2) agronomic—growth of suitable crops in rotation and (3) chemical—application of chemical correctives at calculated dose of soil requirement of gypsum or calcium chloride or a combination of mechanical and agronomic or chemical and agronomic practices. A more scientific classification of saline and alkali soils or *reh*—infested lands of the province in order to prescribe appropriate measure of remedy is, however, necessary. Dhar and Mukherjee (1936) had been successful in reclaiming *usar* soils of U.P. by application of heavy doses of molasses (at 10–15 tons per acre).

Recently, Agarwal and Yadav (1954) studied the saline and alkali soils of the Indian Gangetic alluvium in U.P. with a view to appraising their salinity status *vis-a-vis* the possibility of their reclamation. They examined a number of soil samples from profiles representing typical saline and alkali soils of the Gangetic alluvium. Out of nine profiles studied by them six were from areas that were not previously cultivated and the other three were from cultivated areas of the adjoining district where soil salinity was slowly becoming a problem. The typical profiles from the uncultivated areas had characteristics quite different from one another particularly with respect to their internal drainage caused by (1) heavier calcareous sub soil, (2) pans in sub-soil of hard indurated CaCO_3 nodules cemented together, (3) clay pan subsoils or (4) *kankar* (CaCO_3 concretions) pans rendering internal drainage difficult. They found these soils to be highly alkaline (pH 9—11)

and characterised by almost complete absence of gypsum even though zone of accumulation of stable and nodular CaCO_3 in the profiles was always encountered. Most of the profiles showed characteristics of carbonate-chloride type of saline-alkali soils. They opined that these soils could not be reclaimed by the mere process of leaching even on improving internal drainage as in absence of gypsum there was no readily available source of calcium compounds for exchange reactions in the soils themselves. Besides, for reclamation purpose, a fairly high concentration of carbon dioxide need be maintained in the soil system or an acidifying amendment be used. For cultivated lands, the three profiles represented the three stages in internal drainage. Two of these profiles revealed the usual features of normal cultivated land with no salinity or alkali while the third suggested possible future danger from accumulation of salts, the top soil resting on sub-soil which had already been saline alkali or saline in nature.

At Chakeri near Kanpur an Usar Reclamation Farm of about 60 acres has been started in 1951 under the U. P. Government Usar Soil Reclamation Project. The soils of the farm and of the surrounding areas are highly alkaline (pH—11.0), rich in soluble salts and are of the saline-alkali type of the second grade characterised by a hard clay pan in the sub-soil and absence of vegetation. Morphological studies reveal presence of grey coloured top soil (sandy loam) resting on a hard clay pan with a good sandy soil underneath. Successful reclamation has been achieved by mechanical shattering of the underlying hard clay pan supplemented by leaching with sewage water. Through this operation, downward water movement could be established and the land could be made to part with a substantial portion of its salt contents. Rotational cropping with *metha* late—paddy—barley or oat further improved the soil condition. In three years of judicious management of these soils, the pH values could be lowered from 11 to 9.5, salt content from 0.59 to 0.2% and significant drop in exchangeable sodium could be affected and the yield of paddy crops taken on the land gave an average of 14 mds to 27 mds per acre. This farm would serve as a model for reclamation of soils of this type (Agarwal—private communication).

Kallar is one of the major problems of the Punjab plains. Canal irrigation has resulted in a marked rise of water table owing to semi-arid conditions, the downward movement of salts is very much less than the upward movement with the result that the salts (chiefly sodium salts) accumulate in high concentrations at or near the surface. The sodium of the salts enters the clay complex to form sodium clay by the displacement of calcium. Puri (1934) characterised the Punjab soils by the presence of sodium in the soil complex and emphasizes that replaceable sodium may be the limiting factor in the yield of different crops. Dalip Singh and Nijhawan (1932) have studied the mechanical and chemical composition of the Punjab soil and have shown that high proportion of divalent bases contributes to soil fertility and the *kallar* trouble is mainly due to deficiency of exchangeable calcium. The only method of improving these soils is either by the addition of Ca-salts or by making use of the reserve calcium already present in the soil. Reclamation has been affected by application of gypsum or calcium chloride at the rate of two tons per acre followed by farmyard manure. Puri, Taylor and Asghar (1937) consider the degree of alkalisiation to be useful in classifying the degenerated soils of the Punjab and accordingly five distinct types have been classed for the purpose of reclamation and management.

A scientific soil survey of culturable waste lands of the Karnal district, Punjab, based on modern genetic methods is in progress at Experimental Research Station, Nissang since 1951. The salt contents of these soils are high (to the

extent of 1%) throughout the depth of the profile. The accumulation at the surface is characterised by a high percentage of Na_2CO_3 , a peculiar feature of Karnal soils. The pH values are usually high mostly above 10.0 indicating a high degree of alkalisation. Presence of *kankar* in the soil is invariable although in some areas it is in course of formation and is related to alkalisation and buffering of soils. These soils may be considered as black alkali. Various reclamation methods have been tried on these soils. The chemical correctives, e.g., H_2SO_4 and gypsum have yielded good results, but the dose at which favourable response has been obtained is high and expensive. By a system of cropping with salt resistant plant species, some reduction in pH values of the soils as also conversion of Na-clay of the soil to Ca-clay which contributes to fertility has been made possible. The crop that has been found to be most useful is *jantar* (*Sesbenia aculeata*). This is a quick growing plant and can stand a fairly high degree of alkalinity in the soil. Its roots generate a considerable quantity of carbon dioxide which is helpful in converting sodium carbonate to bicarbonate. When the crop grows to a height of 4–5', it is ploughed in, preferably underground. During decomposition of the green plant a considerable quantity of CO_2 is generated and it helps converting Na-clay into Ca-one. Rice is another crop showing similar ameliorative effects and a large area of Indri Reclamation Farm is generally under rice. After a crop of *jantar* or rice, the alkalinity becomes a bit reasonable and it is possible to raise a crop of sugarcane which further improves the soil condition. Application of ammonium sulphate to rice and sugarcane further helps in reducing alkalinity.

Saline and alkali soil conditions exist over a considerable area of the Bombay-Deccan. In the Deccan a very large area has been affected due to the construction of the Deccan canals. Round the Gulf of Cambay in Gujrat considerable land is affected by sea-tides carrying salt laden silt and depositing on the surface. In Surat, Broach and Ahmedabad the soils under tidal influence show high content of monovalent bases and of magnesium and a predominance of chlorides in total soluble salts amounting to more than 50%. The reclamation of these lands by bunding and leaching of soluble salt is possible.

Portions of Dharwar district and Bijapur taluks are affected by what is known as *karl* soils which are saline and alkaline and fairly deep and clayey. The salt lands of the Nira valley have developed as a result of excessive irrigation given on deep black soil of the locality. Mann and Tamhane (1910) have shown that these salts are derived from the decay of the trap itself as evident from the presence of sulphate and chloride of sodium with varying quantities of magnesium salts in the disintegrated rocks. Basu and Tagare (1943) studied a large number of alkali soil profiles based on morphology on the six major canals of the Deccan. They were able to distinguish two groups of profiles according as the A or both A and B horizons were rendered compact and impermeable. These soils whether situated on flat topography or occurring in low-lying situation have sub-soil water table at 10–15' depth. The profile features of the former resemble those of Steppe alkali soils whereas those of the latter the solonetz. The salinity (alkali) status of these two alkali soil profiles of the Bombay-Deccan is given in Table II. The common characteristic of these soils is the high saturation of the surface soil with sodium base and a zone of accumulation of salts in the profile responsible for development of structure—profile. Basu and Tagare (*loc. cit.*) succeeded in reclaiming some of these soils with porous B horizon by creating humid condition by irrigation and subsequent agronomic management. In the worst type of alkali soil where both A and B horizons were rendered compact and impervious they

found a mixture of sulphur (at 1/2 ton per acre) and farmyard manure (at two tons per acre) to be the best reclaiming agent.

The damaged land of canal irrigated tracts of the Bombay-Deccan was studied by Talati (1941) with particular reference to their salt content, exchangeable bases and pH. He classified these soils into (1) mixed saline soil (containing a mixture of Ca-, Mg-, and Na-salts, the last named tending to increase with depth), (2) saline soil (containing mostly Na-salts with higher pH than the first) (3) alkali soil* and (4) strongly alkali soil according to the presence of different amounts of soluble salts in the soils and their pH values. The saline soils of the Bombay State have been grouped into three classes (Basu, 1950) according as they are formed under natural arid and semi-arid conditions, irrigation and salt bearing parent material or beds affected by sea water in the past or by extensive flooding of sea water.

In the State of Madras, intensive soil survey has been conducted from the viewpoint of irrigation. These soil surveys in connection with various irrigation projects have been either (1) pre-irrigational or (2) post-irrigational. The latter was necessitated by some troubles arising out of previous irrigation projects. Irrigation of black cotton soil was frequently questioned and as a consequence a large stretch of black cotton soil in Madras was surveyed in details before bringing the area under the command of the Tungabhadra. Such studies revealed the occurrence of gypseous and non-gypseous profile development. The salt content of the black soils ranged from 0.1 to 0.5% within the first three feet zone and was considered harmless. The base status of the black soils was high with 40–60% of exchangeable calcium and the degree of alkalisiation below 25% in most cases was considered safety limit. The morphological features of two black soil profiles are cited below (Tungabhadra Project Survey) :—

GYPSEOUS BLACK SOIL PROFILE FROM SIDDAMMANAHALLI

Depth of Horizon in inches	Description
0—24	Black, clayey, with columnar structure, top 2" friable and the rest hard and compact.
24—72	Whitish black, clay loam, columnar structure, <i>kankar</i> nodules and crystals of gypsum present, slightly hard. The <i>kankar</i> increases with depth.
72—96	Whiter than above, sandy, with patches of pale cement, highly weathered granite.

NON-GYPSEOUS BLACK SOIL PROFILES

0—12	Black, loamy, columnar structure, easy to work.
12—36	Black, clay loam, columnar structure, hard.
36—60	Black, clay loam, columnar structure, with concretion of CaCO_3
60—72	Greyish black, clay loam, columnar structure, bits of <i>kankar</i> with stray bits of gypsum.
72—80	Mixture of bits of <i>kankar</i> and infiltrated grey soil—ferruginous gravel present.

*Stiff soils with low salt content at the top and varying degrees of alkalisiation, the pH being above 9.0 and carbonates in great preponderance.

The areas of black soils which have been irrigated with the Tungabhadra water (containing 20 part solids per 100,000) have not developed alkalinity, whereas similar soils irrigated from other sources like Chinna Hagari river, etc. which contain large amounts of soluble salts developed alkalinity and deteriorated. From the above observations it is evident that black soils can be irrigated to benefit provided the water is good and utilised with care.

Ravchaudhuri and Sharma (unpublished) studied some typical saline and alkali soil profiles of south India. The locations from where these profile samples were collected are as follows :—(1) near the Coimbatore farm, (2) near the Padegaon Farm and (3) village Hol. Morphologically, the profile, collected from near the Coimbatore farm, was characterised by presence of columnar structure, a compact sub soil and calcareous nodules increasing with depth. The profile could be distinguished into three horizons, *e.g.*, A and B and B₃ giving it a "solonetz" like appearance. In a similar way the village Hol profile had a compact B horizon and was characterised by presence of angular chunks and clods becoming lumpy below distinguishing into two clear horizons, A and B. The profile from near the Padegaon farm had morphological features revealing existence of two horizons, *e.g.*, A and B. The second horizon was mottled brown, fairly porous and had heavy deposits of lime. The salinity status of two profiles is given in Table III. Chemical analysis of Coimbatore profile samples (Table III) showed a high content of sodium in exchange complex varying from 34—52% and the pH was above 10 in the first three layers. The degree of alkalinisation was high. Morphological features and physico-chemical properties pointed to the fact that this soil could be classed under "solonetz" or "black alkali" mixed with "white alkali."

The Padegaon profile had a high lime status and contained soluble salts throughout the profile with an accumulation at the surface (0.52%, Table III). The pH of the soil in all horizons was round 9.5. Calcium/sodium ratio varied from 12.47 to 28.57 in the profile. Chemically and morphologically the soil was nearer to "solonchak" group of classification.

Raychaudhuri and co-workers (1952-53) studied the saline soils of the Delhi State. Salinity which mitigates crop growth or totally prohibits it, is responsible for rendering a considerable percentage of land of the state as waste and unfit for cultivation.

This study served as a pre-irrigational survey, since these areas were proposed to be irrigated by sewage effluents in the near future. Some typical profiles of Jumna *khadar* (new alluvium) area both from the north and south representing the different degrees of salinity were studied. The profiles were characterised by absence of horizon differentiation and structural formations. Textural variations with depth, however, formed the basis of differentiation. The salinity status of some soil profiles of Jumna *khadar* north and south has been given in Table IV. In the north *khadar* area, the profile depth was conditioned by sub-soil water table varying from 36" to 66". The salinity of these soils was largely of sodium chloride and sulphate and similar condition but of higher magnitude was found in the underground water (Table IV). Thus the rise of salts in the profiles might be traced to the upward movement of underground water. The pH of all the soils was on the alkaline side but below 9.0. The soils were base saturated and the percentage of sodium in exchange complex of the soils varied between the maximum values for white alkali soils and minimum values for black alkali soils. Morphological

features and physico-chemical properties suggested that these soils belonged to "solonchak" group of classification.

The south *khadar* profiles had high salt concentrations and efflorescence at the top which represented the average condition of salinity of the whole tract. The total soluble salt was maximum at the top decreasing with depth. The reaction of the soil was slightly alkaline the highest pH being 8.1. The cation exchange capacity of the soils was low but varied directly with clay content. The exchange complex was fully base saturated and sodium had gained considerable entry into it. The soil could best be classed as structureless saline-alkali soil.

The reclamation of these lands consisted in washing away of the soluble salts by water of good quality by improving drainage conditions and then raising salt resistant crops like rice, barley and berseem. Application of sulphur at appropriate doses would work as an useful ameliorative agent.

The soils of the sea-coast are saline and reclamation consists in exclusion of tidal salt waters. The problem of reclamation of the saline soils of Rann of Cutch is similar to that of Zuyder Zee in Holland.

TABLE I

Salinity (alkali) status of a typical alkali soil profile of U. P. (Agarwal and Mehrotra, 1952)

Locality	Local name	Horizon	Total soluble salt %	Carbonates as Na_2CO_3 %	Bicarbonates as NaHCO_3 %	Chloride and sulphate of Na %	pH	Cation exchange capacity m.e./100 gms soil	Exchangeable bases m.e./100 gms soil		Na saturation %
									Ca	Na+K	
Pachpera,	Usar	1st	1.61	0.39	0.40	0.75	9.6	10.20	...	10.2	100
Aligarh	(Reh)	2nd	0.50	0.11	0.16	0.20	9.5	20.76	1.0	19.6	94.4
Distt.		3rd	1.23	0.33	0.29	0.58	9.3	15.32	1.0	13.3	86.9
U. P.		4th	0.32	0.09	0.14	0.03	9.4	13.44	1.4	11.84	88.1
		5th	0.22	0.03	0.15	0.01	8.2	10.44	2.6	7.04	67.4

TABLE II

Salinity (alkali) status of two typical alkali soil profiles of Bombay-Deccan (Basu and Tagare, 1943)

Locality	Local Profile name No.	Horizon and depth in inches	Total soluble salts %	Na ₂ CO ₃ %	pH	Exchangeable bases m.e./100 gm soil		Ca:Na ratio
						Ca	Na	
Situations on the Deccan canals, Bombay-Deccan	1	A 0-12	0.69	0.011	8.91	35.75	5.80	6.10
		12-24	1.14	0.011	8.83	26.00	16.13	1.61
		B ₁ 24-32	1.48	0.011	8.69	22.50	16.13	1.39
		B ₂ 32-56	1.48-1.31	0.016-0.021	8.69	20.5	16.13	1.27
2		C 56-68	1.04	0.021	8.84	11.0	14.93	0.74
		A 0-12	0.31	...	8.76	31.50	5.66	5.57
		12-24	0.93	...	8.66	24.50	11.52	2.13
		B ₁ 24-58	1.90	0.011-0.016	8.54	31.50-26.50	11.85-11.52	2.65-2.30
B ₂		58-84	2.80-2.40	0.005-0.021	8.33	37.00-25.00	8.86-8.76	4.18-2.85
					-8.61			

TABLE III

Analytical results of saline and alkali soil profiles of south India (Raychaudhuri and Sharma, unpublished)

Locality	Profile No.	Depth in inches	Total soluble salts %	Carbonate %	Bicarbonate %	Chloride %	Sulphate %	pH	Cation exchange capacity m.e./100 gm soil	Exchangeable bases m.e. 100 gm soil ratio	
										Ca	Na
Near Coimbatore farm	1	0-3	1.04	0.17	0.21	0.08	0.23	10.1	25.4	13.2	9.45
		3-15	0.93	0.24	0.28	0.05	0.23	10.3	29.9	16.5	20.8
		15-27	0.68	0.20	0.32	0.04	0.02	10.2	43.5	18.7	20.6
		27-39	0.47	0.14	0.17	0.01	0.02	9.8	29.7	13.03	10.05
Padegaon farm	2	39-51	0.30	0.08	0.09	0.01	Trace	9.75	—	9.96	9.35
		0-6	0.52	0.02	0.13	0.02	0.27	9.5	46.8	37.4	3.0
		6-14	0.45	0.03	0.11	0.02	0.24	9.55	47.5	39.1	2.4
		14-22	0.42	0.02	0.11	0.02	0.20	9.5	46.95	40.0	1.4
		22-34	0.39	0.02	0.08	0.01	0.22	9.4	41.5	35.6	1.5
											23.73

TABLE IV

Salinity status of some degenerated soil profiles of the Delhi State (Raychaudhuri and co-workers, 1952-53)

Locality	Profile No.	Depth in inches	Total soluble salts %	Carbo-Bicarbonate		Chloride %	Sulphate %	pH	Cation exchange capacity m. e./100 gm soil	Exchangeable bases m. e./100 gm soil			Na saturation %		
				%	%					%	(Ca+Mg)			Na	K
											Na ₂ SO ₄ of total solids	NaCl of total solids			
Jumna Khadar (North) Delhi	1	0-12	1.66	52.80	...	8.14	12.48	8.41	3.53	0.54	28.29		
	12-44	0.91	...	...	69.65	...	8.23	10.14	8.07	1.61	0.46	15.88	
	44-66	0.57	...	...	70.86	12.03	8.45	8.29	6.10	1.76	0.43	21.22	
	*U.G.W.	2.28	...	...	56.35	...	8.52	...	...	...	...	...
	0-9	0.30	...	...	36.80	28.91	8.80	13.87	11.76	1.52	0.59	10.95	
2	9-18	0.47	...	...	36.47	25.74	8.16	15.55	13.63	1.18	0.74	7.59	
	18-27	0.33	...	...	32.05	27.66	8.25	7.35	5.67	1.34	0.34	18.23	
	27-36	0.32	...	...	63.80	22.02	8.40	6.06	2.50	3.30	0.26	54.45	
	*U.G.W.	1.14	...	...	61.39	...	9.06	...	...	...	...	...
	0-7	0.39	...	0.037	0.15	0.07	8.1	5.29	1.90	1.48	1.91	28			
Jumna Khadar (South) Delhi	7-10	0.13	...	0.037	0.01	0.04	7.8	5.70	3.70	1.00	1.00	17			
	10-11	0.13	...	0.031	0.02	0.03	7.2	3.03	...	1.91	1.90	50			
	11-13	0.16	0.006	0.031	0.03	0.04	7.7	3.98	1.94	0.64	1.40	16			
	13-19	0.16	...	0.018	0.05	0.04	7.2	2.20	0.83	0.43	0.94	22			
	19-21	0.14	0.006	0.031	0.03	0.03	7.6	4.08	1.63	1.51	0.94	37			
	21-40	0.11	...	0.024	0.01	0.04	7.3	2.26	0.64	0.62	0.99	27			
	Surface	0.90	0.018	0.037	0.32	0.26	8.1	5.15	2.59	2.57	...	51.8			
	0-3	...	...	...	...	...	...	...	...	...	...	...
	0-11	0.18	...	0.043	0.049	0.032	7.9	5.79	3.45	1.08	0.27	18			
	11-16	0.13	0.006	0.043	0.021	0.018	8.1	8.82	6.69	0.96	1.17	10			
Jumna Khadar (South) Delhi	16-17	0.11	0.006	0.046	0.009	0.017	7.8	4.28	1.37	1.01	1.91	23			
	17-19	0.13	0.006	0.043	0.01	0.028	7.9	10.05	7.73	1.63	0.70	16			
	19-23	0.09	...	0.024	0.014	0.022	6.8	1.9	0.27	0.95	0.71	49			
	23-28	0.07	...	0.024	0.007	0.014	6.8	2.8	1.55	0.04	0.21	1			
	*U. G. W.—underground water.														

*U. G. W.—underground water.

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ON ACID SALINE SOILS OR SULPHATE SOILS

By

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There are three kinds of saline soils : alkaline, neutral and acid. The acid soils contain sulphates and are in consequence called sulphate soils. When aerobic they are very acid.

The largest areas of sulphate soils in Finland are to be found mainly in the costal regions, in the so called Litorina district. Sulphate occurrences are most frequently met with in the youngest geological marine sediments, *e.g.*, in gytja or muddy soils. Small patches of sulphate soils can sometimes be found also in glacial soils in the interior of the country. In the last few years fairly large areas of peat soils containing a lot of salts have been found in the north of Finland. Sulphate soils in natural state occur in Finland only in very low places, the drainage of which would be both difficult and expensive. During the last 20—30 years sulphate soils have been reclaimed on a vast scale. Owing to drainage and cultivation the salts have been leached from the soil and thus also the reaction has become more suitable for cultivated plants. In many cases such soils have given rise to very good fields.

Except for Finland sulphate soils are found to some extent also in Sweden and even there principally in the costal regions (*Hannerz*). A formation of similar kind is known also in Norway (*Lag*). In Denmark and in Germany the same kind of soils have been met with when digging canals and drains. The "kattieklië"—occurrences in the Netherlands resemble sulphate soils in character. It is interesting to learn that sulphate soils have recently been found in tropical areas *e.g.*, in Uganda (*Chenery*).

Some chemical analyses of the water soluble salts found in sulphate soils in Finland and Sweden are reported in table 1. The amount of these salts varies naturally very much depending on the weather. During a dry period the salts will accumulate to the surface of the soil, but in wet weather rainwater leaches them down. The concentration of salts can in uncultivated lands reach 2.45% but usually it is considerably under 1%. The chemical composition of the salts varies very much. As a rule they contain plenty of sulphates but usually scantily of chlorides. The amount of calcium and magnesium as well as that of aluminium and iron fluctuates on a great scale.

The distance between the samples from Isokyrö, mentioned in the table, was only about 60 metres. This indicates how the concentration of salts can vary even in a small area. A similar phenomenon can be observed in an area, recently reclaimed, at Liminka in the north of Finland. The soil samples taken from a

canal, from a salt patch, and from the surface layer of the field contained salts in water soluble form as follows:—

Soil samples taken from—	pH	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ %	CaO %	SO_3 %	Cl %
the canal	3.90	0.01	0.39	0.47	0.02
the salt patch depth 0—3 cm	3.35	0.23	1.48	3.35	0.57
the field depth 0—20 cm	5.07	trace	0.31	0.19	0.11

The salts found in sulphate soils are rather easily soluble and thus it is possible to leach them from the soil. In order to find out the rapidity of leaching, 50 grams of sulphate soil was washed four separate times in a funnel and the filtrates were analysed. The reaction of the original soil sample was pH 3.91. The pH-values and the amounts of sulphates, aluminium, and iron in the different filtrations were as follows:—

	pH of the soil	pH of the filtrate	SO_3 mg	$\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$ mg
1. Leaching/500 ml water	4.91	4.75	342.0	52.0
2. „ /250 „ „	4.66	4.95	58.0	10.5
3. „ „ „ „	4.75	5.12	3.8	10.5
4. „ /1000 ml „	4.89	5.18	7.2	6.0

It can be seen that the first 500 ml of water leaches a lot of sulphates and also of aluminium and iron. At the same time the pH value rises very strongly. The latter filtrations contain smaller quantities of all the substances; and also the changes in the reaction are smaller. Similar results have been published by the author earlier (Kivinen, 1950).

The sulphate soils have a very characteristic reaction. When water saturated and in anaerobic conditions this kind of soil gives very high pH values, usually over pH 7. But when the soil is oxidized its reaction quickly turns very acid, sometimes so that nothing or only species such as *Spergula arvensis* and *Epilobium angustifolium*, which thrive in very acid conditions, will grow there. As an example may be mentioned some pH values obtained from a sample of 0.5 m³ of sulphate soil, which was taken from 2 metres deep and which was lying in the field under the influence of the weather (table 2). Besides the pH values also the amounts of the water soluble salts in the sample have been determined.

The original reaction of the soil was about pH 8. When taken in winter time the soil sample probably froze immediately so that no chemical reaction took place. In spring, however, the pH values dropped clearly. In one year the soil became very acid. Later on the pH values began to rise in consequence of the leaching of acid salts. The same happens when sulphate soils are drained for cultivation. Then it is not uncommon to have pH values of about 3.

The figures above show also that under anaerobic conditions there is a relatively scanty supply of water soluble salts in the sulphate soils, but in oxidized samples their amount increases very strongly. This is due to the fact that in the

former case sulphur compounds are mainly in the form of sulphides and in the latter case again in the form of sulphates. This becomes apparent also from the fact that the colour of the layers of sulphate soils below the groundwater level is more or less black because of iron sulphides. Neither is it rare to observe in them the distinct stink of sulphurated hydrogen. When oxidized the black layers lose their colour and they become grey or rusty brown.

When sulphate soils are being reclaimed an effective drainage is naturally necessary. Special attention has to be paid to groundwater, which must never rise up to the surface, for it can bring acid salts again to the surface of the field. So large an amount of the salts in the upper layers of the soil are usually leached during 5—10 years that cultivated plants will begin to thrive there. It is recommended, however, that in the beginning of cultivation such species are grown as tolerate acid conditions *e.g.*, oats, rye, potatoes and timothy. Later on when the concentration of the salts has gone down and the reaction improved, also more pretentious plants begin to thrive there. There are large areas of sulphate soils in Finland which nowadays give excellent yields.

Because of their high acidity sulphate soils need necessarily lime when reclaiming. 4—5 tons per hectare at a time is the amount usually recommended, but the procedure must be repeated after some years. Also the fixation of phosphorous in sulphate soils is very strong, therefore a large amount of phosphate fertilizers (1000—1500 kilos/hectare) is recommended. A large quantity of nitrogen must be used also because the mobilisation of nitrogen in this kind of soils is usually very slow. Stable manure produces as a rule a very good effect.

TABLE I

Chemical composition of the water soluble salts of some sulphate soils (%)

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	CaO	MgO	K ₂ O	Na ₂ O	SO ₂	Cl	Water solu- ble salts in soil %	pH
Finland (<i>Prosterus</i>)												
Paimio	2.97	0.30	...	...	8.44	8.84	1.66	21.67	46.66	...	0.48	...
Halikko	4.49	9.68	3.60	...	5.76	3.94	2.90	5.35	44.32	...	0.51	...
Isokyrö	6.12	1.60	5.65	...	11.11	9.39	2.13	3.67	42.75	...	0.50	...
Ylistaro	1.89	8.20	5.21	...	4.52	6.79	1.64	5.07	45.24	...	0.71	...
Isokyrö, uncultivated soil (<i>Aarnio</i> , 1922)												
0—10 cm	0.29	10.77	1.31	...	23.77	1.65	0.41	4.16	56.78	0.85	2.45	3.9
10—20 „	...	7.32	...	...	13.24	6.92	...	16.42	48.84	7.12	0.20	5.1
25—35 „	12.26	3.66	...	...	12.44	10.89	1.46	7.32	48.76	3.20	0.22	5.2
Isokyrö, cultivated soil (<i>Aarnio</i> , 1922)												
0—30	0.94	2.41	...	...	17.34	13.94	0.87	14.94	45.58	4.22	0.30	4.7
30—40	5.01	2.28	...	...	7.06	14.41	...	3.39	67.66	1.59	0.20	4.2
45—55	6.25	7.47	...	...	11.55	12.83	...	11.48	48.00	2.38	0.28	4.3
Sweden (<i>Hannerz</i>)												
Rosvik	...	14.97	3.49	0.92	2.30	10.34	...	...	68.0	...	0.73	3.0
Sunderbyn	...	9.78	11.65	1.71	4.33	3.32	2.09	0.53	66.6	...	0.19	2.9
Hindersön	...	11.26	4.35	0.63	8.17	7.69	0.51	...	67.3	...	0.43	2.6
Lappön	...	11.10	18.00	1.40	2.30	5.80	...	...	61.3	...	...	3.4

TABLE 2

pH values and the amount of electrolytes in the different layers of a sulphate soil sample

Depth cm	0—2	2—5	5—10	10—20	20—
	pH values				
27.3-1936	..	7.96	...	8.07	8.08
7.5-1936	7.51	8.34	8.27	8.26	...
20.6-1936	3.89	4.29	4.35	4.31	...
18.9-1936	4.00	3.58	3.57	3.40	4.30
22.5-1937	2.51	2.58	2.63	2.85	3.26
3.10-1937	3.61	3.35	3.33	3.57	3.60
1938	3.50	...	...	...	...
1939	4.10	...	..	...	...
1943	4.10	...	...	...	...
1945	4.30	...	...	...	...
	Electrolytes mg/ l				
27.3-1936	...	1562	...	1275	1350
7.5-1936	1875	945	775	716	...
20.6-1936	5500	3700	3500	3200	...
18.9-1936	7300	7800	4160	3800	...
22.5-1937	14200	4590	3770	3770	3060
3.10-1937	10000	5000	2800	2800	2500
1938	2000
1939	500
1943	700
1945	175

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RECLAMATION OF ALKALI SOILS

By

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One of the most characteristic features of the arid zone soils is their tendency to develop salinity. The soils have an alkaline reaction and contain mostly sodium salts.

Three types of salts, *viz.*, sulphate, chloride and carbonate of sodium usually form the main mass of the saline efflorescence. The main types are the following :—

(a) *Solon chak*—Saline soils, containing sodium carbonate (black-alkali) or sodium sulphate and sodium chloride (white alkali).

(b) *Solonetz*.—Alkaline soils, belonging to high pH and low soluble salt content type.

These soils are distributed among the normal (zonal) soils of the arid regions of the earth's surface. Large areas are lying waste in the Punjab, U. P. and other States of India. In U. P. the alkaline soils are known as "Usar" soils.

The formation and reclamation of saline soils by irrigation and paddy cultivation and its effect upon the soil nutrients has been dealt with by Mehta,⁴ Taylor⁶ and Asghar, and Dhawan.¹ The reclamation of alkali soils is confronted with great difficulties. It is almost universally recognised that the poor structural qualities of alkali soils are due to the adverse physical conditions produced by the excess of exchangeable sodium. It is also an accepted fact that the sodium soils are highly hydrated and dispersed than calcium soils. The former swell and become impervious. The problem, therefore, is to investigate some practical and cheap method for producing favourable physical conditions. This can be accomplished by replacing sodium in the exchange complex by calcium. It can be done by any one of the following methods :—

(a) Addition of soluble calcium salts like calcium sulphate and calcium chloride etc., etc.

(b) To make available calcium present in the soil in the form of calcium carbonate by lowering the pH value.

(c) Green manuring or other materials which on oxidation can lower the pH value and replace the exchangeable sodium by calcium.

The present paper presents the results of semi field experiments carried out with different reclaiming agents for investigating the most suitable but practical method for the reclamation of alkali soils.

EXPERIMENTAL

Experiments were conducted in plots of ten feet by six feet each. The variation in total soluble salts and pH of the soil with depth is given below :—

TABLE I

Showing the variation in total soluble salts and pH of soil with Depth

Serial No.	Depth	Total soluble, salt (Na_2CO_3) %	pH
1.	0—1 ft.	0.57	10.50
2.	1—2 ft.	0.47	10.40
3.	2—3 ft.	0.10	9.20
4.	3—4 ft.	0.08	9.00
5.	4—5 ft.	0.08	8.97

The following treatments were given :—

- (1) Leaching.
- (2) Leaching with hoeing.
- (3) Sulphuric acid at 0.65 ton and 6.6 tons per acre.
- (4) Gypsum at 3.3 tons per acre.
- (5) Lime sludge (6.4 tons per acre) with molasses (1.6 tons per acre). Both are waste products from a sugar factory.
- (6) Distillery waste (a waste product from distillery factory) at 103 tons per acre.
- (7) Farmyard manuring at 26.5 tons per acre.
- (8) Calcium chloride at 3.2 tons per acre.
- (9) Farmyard manure (26.5 tons per acre) plus distillery waste (26 tons per acre).
- (10) Addition of green manure (20 tons per acre).

The crop rotations carried out in each plot were rice, berseem (*Trifolium-Alexandrinum*).

DISCUSSION OF RESULTS

The pH value and the total soluble salt contents are the two essential factors, which need specific control for maintaining the fertility of a soil. Taylor⁶ laid down limits of fertility and deterioration of soils in relation to their total salts and pH. It was concluded by him that if the salt content of the soil exceeded 0.2% and the alkalinity exceeded pH value of 8.5, then the soil deterioration would set in and crop yields would be below normal.

Fig. I shows the relation between the variation in total soluble salt and pH of soils with depth, treated with different reclaiming agents after third year. The following main inferences were drawn from this study :—

- (i) The reclamation of soils infested with sodium carbonate is a very slow process.

(ii) The following is the order of efficiency of the different reclaiming agents.

(a) *Distillery waste*.—It is a waste product from alcohol factories. Its pH ranges between 4.5 to 4.9. Due to its acidic properties, calcium carbonate present in soils become soluble and the reverse reaction of the replacement of sodium by calcium begins to take place. It is well known that only about one milliequivalent of calcium carbonate is soluble at pH 8.6, while over 70 are soluble at pH 7.⁵ Distillery waste also contains a little calcium, which can help in removing some of the sodium from the exchange complex. Even in the first year of reclamation distillery waste and lime-sludge plus molasses behaved the best.²

(b) *Farmyard manure plus distillery waste*.—In this case the pH at lower depth was not affected much. The release of complex organic acids from the farmyard manure counteracted the adverse effect of the sodium ions at lower depths.

(c) *Green manuring by Jantar (Sesbania—Articulata)*.—It was investigated by Dhawan, Malhotra and Singh³ that the root system of this plant could be used as a field method for judging the effectiveness of a particular reclaiming agent for black alkali soils. With the use of this type of green manuring, it was observed (Fig. I) that the released sodium ions from the top could not raise the pH of the soil at lower depths due to the production of complex organic acids. This confirmed the results of farmyard manure discussed under (b).

(d) *Farmyard manure and molasses plus lime sludge also did quite well*.—It is an established fact that organic manures on decomposition emit certain complex organic acids, which, therefore, help in replacing the sodium by calcium in the exchange complex.

(e) *Gypsum* was comparatively more effective than the calcium chloride. The low solubility of calcium sulphate is responsible for its better reactivity than calcium chloride.

(f) *Leaching with hoeing* displayed greater reactivity than simple leaching. This confirmed the results of Dhawan, Malhotra and Singh that for the reclamation of sodium carbonate soils, hoeing was an essential step for bringing the chemical reaction of the displacement of sodium by calcium.³

(g) In other cases the effect was not very prominent. Even the sulphuric acid alone could not completely neutralise the alkalinity.

From the results of analysis of soil samples after three years of reclamation operations, it was concluded that crop rotation alone was a very slow process for reclaiming such type of soils. (Black alkali.)

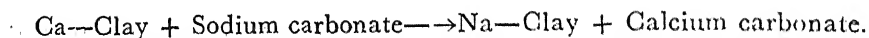
Some kind of chemical was needed to start the reaction in the opposite direction.

The above conclusions were further supported by the yield figures. The yield of rice fell in the following order :—

1. Distillery waste.
2. Lime sludge plus molasses.

3. Green manuring.
4. Farmyard manure with distillery waste.
5. Sulphuric acid.
6. Farmyard manure, gypsum and calcium chloride.

The interesting observation noticed was the increase in pH of soils below two feet depth. This was quite evident, as sodium carbonate being an alkaline salt would immediately start base exchange reaction. Sodium carbonate leached out gradually increase the sodium in exchange complex. This reaction may be explained schematically as follows :—



What is really needed in the reclamation of black alkali soils which are highly impervious and hard, is to improve the structure of the top few inches, so that rice-seedlings which is a well-known alkali resistant plant may get itself established. For the reclamation of saline soils the recommended technique is leaching followed by rice cultivation and some type of leguminacea crop.¹ But the sodium carbonate soils resist leaching. Therefore hoeing is a very necessary step for accelerating the speed of reclamation in the case of black alkali soils. It has already been confirmed (Fig. I).

The next point which merits the attention is about the quantity of calcium salt actually required for reclamation. The Punjab and U. P. soils are mostly kaolinite and their base exchange capacity lies between 10 to 20.0 milliequivalents per/100 grams of soil. Taking the worst case, let the whole of the exchange complex is charged with sodium and the soil possesses the maximum base exchange capacity i.e., 20. To replace the whole of sodium by calcium, only 1% of calcium carbonate is needed, which may be present in the arid zone soils. Therefore the problem of reclamation of black alkali soils is not very intricate. It needs proper crop rotations and patience if no other chemical is available nearby.

SUMMARY

(i) Any one of the following treatments may be used for the reclamation of black alkali soils. But the decisive factor in the selection of the reclaiming agent is its cost :—

- (a) Distillery waste,
- (b) Lime sludge plus molasses.
- (c) Farmyard manure plus distillery waste.
- (d) Green manuring.
- (e) Calcium sulphate.
- (f) Calcium chloride.

(ii) Hoeing accelerates the reclamation process.

(iii) The alkalinity of soils at lower depths increase gradually due to the removal of calcium from the exchange complex by sodium ions released from the top.

(iv) For maintaining the fertility of alkali soils, it is, therefore, necessary that the crop rotations practised on each type of soils should include green manuring plants along with rice also,

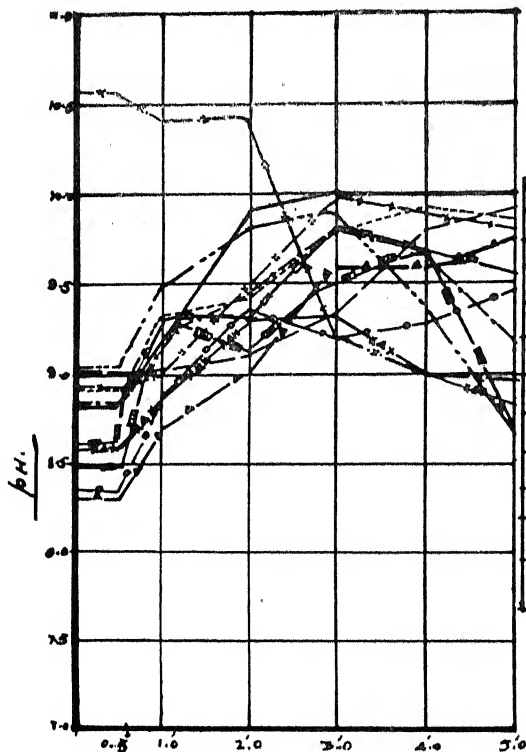
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Graph showing variation in pH and total-soluble salts of black alkali profiles treated with different reclaiming agents

CROP ROTATION

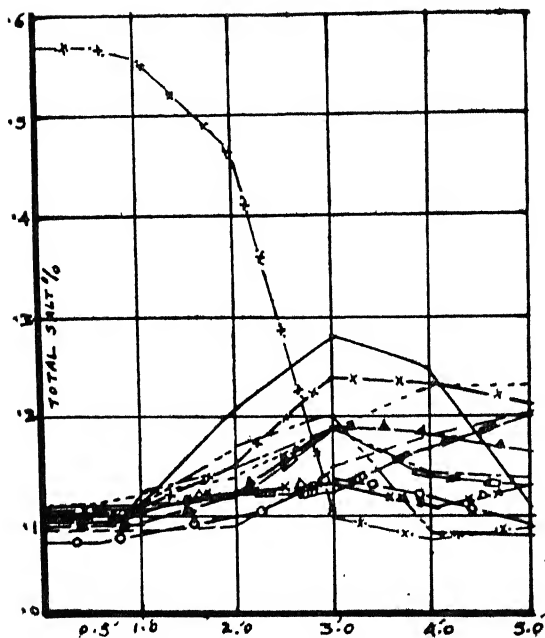
RICE-BERSEEM (*Trifolium-Alexandrinum*)



REFERENCES:-

TREATMENTS.

1.	INITIAL	—X—
2.	SIMPLE LEACHING	—
3.	LEACHING WITH NABING	—•••••
4.	H ₂ SO ₄ @ 6.5 TONS P.A.CRE	—X—
5.	H ₂ SO ₄ @ 6.5 TONS P.A.CRE	—X—
6.	CYPSUM @ 3.3 TONS P.A.	—•—
7.	DISTILLERY WASTE 103 TONS P.A.	—Δ—
8.	LIME SLUDGE 4 TONS + MOLESSES 1.5 TONS P.A.	—□—
9.	CALCIUM CHLORIDE 3.2 TONS P.A.	—•••••
10.	JANTAR GREEN MANURE 20 TONS	—■—
11.	FARM YARD MANURE 20 TONS P.A.	—XAX—
12.	DISTILLERY WASTE @ 2.6 TONS + FARM YARD MANURE 2.6 TONS P.A.	—○—



REFERENCES:-

TREATMENTS.

1.	INITIAL	—X—
2.	SIMPLE LEACHING	—
3.	LEACHING WITH NABING	—•••••
4.	H ₂ SO ₄ @ 6.5 TONS P.A.	—X—
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9.	CALCIUM CHLORIDE 3.2 TONS P.A.	—•••••
10.	JANTAR GREEN MANURE 20 TONS	—■—
11.	FARM YARD MANURE 20 TONS P.A.	—XAX—
12.	DISTILLERY WASTE @ 2.6 TONS + FARM YARD MANURE 2.6 TONS P.A.	—○—

DEPTH IN FEET

PRELIMINARY INVESTIGATIONS ON THE RECLAMATION OF SALINE SOILS BY EARTH WORMS

By

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As early as 1882 Darwin³ observed that earth-worms played a substantial role in the formation of agricultural soils. Since that time some investigations have been carried out on the effects of earth-worms activity on the physico-chemical and biological properties of soils. Wollny¹⁰ showed that earth-worm burrows raised the air-capacity of loam soils from 8.9 to 31.2%. Later on Blank and Giesecke² confirmed the above findings.

Recent researches carried out by Gurianova⁵ and Hopp and Hopking⁶ have shown that earth-worms may play an important role in the formation of water stable soil aggregates. Dawso⁹ also presented evidence that stable aggregate formation took place due to the activity of the earth-worms.

From the above discussion, it appears that earth-worm increase the water stability of a soil. The present investigation was, therefore undertaken to see how far the earthworm activity could ameliorate the saline soils as any improvement in soil structure would naturally lead, to better fertility.

EXPERIMENTAL

The following investigations were conducted.

- (i) Effect of different percentages of sodium salts (usually present in saline soils) on the activity of earth-worms.
- (ii) Effect of earth-worm activity on the dispersion coefficient of soils.

DISCUSSION AND RESULTS

(i) *Effect of different percentages of sodium salts (usually present in saline soils) on the activity of earth worms.*

Three types of salts, viz., the sulphate, chloride and carbonate of sodium usually form the main mass of these saline efflorescence in the arid zone soils. Calcium carbonate is also frequently present in such types of soils.

Artificial soils, containing the following percentages of sodium salts, were prepared.

- (1) Control.
- (2) 0.1% to 1.0% of sodium chloride, sodium carbonate and sodium sulphate.

The mechanical analyses of this soil is given below :—

(a) Clay (Particles below 0.002mm)=15.4%.

(b) Silt (Particles greater than 0.002 mm but less than 0.02 mm)=18.7%.

(c) Sand (Particles greater than 0.02 mm but less than 2.0 mm)=65.6%.

The initial moisture content of these soils was kept at about 15.0%.

The hollow soil cement blocks of 6.0" × 6.0" × 15.0" dimension were half filled with these soils. Fifty earth-worms were placed in each type of soil and the blocks were closed, so that no earth-worm could go out. The earth-worms were counted, three time a day and any deficiency noticed in any block was immediately made up in order to keep the number of earth-worms same in all the soils. The observations were taken for three weeks. The temperature variation during that period was 107°F. (maximum) and 81°F (minimum).

Table I gives the results of the effect of varying percentages of sodium salts on the life activity of the earth-worms.

TABLE I

Showing the effect of varying percentages of sodium salts on the life of earth-worms

S. No.	Salts %	Percentage of earth-worms living in		
		Sodium chloride	Sodium carbonate	Sodium sulphate.
1.	0.0	...	All living	...
2.	0.1	59.0	85	100.0
3.	0.2	12.0	65	100.0
4.	0.3	6.0	35	85.0
5.	0.4	All dead	15	78.0
6.	0.5	Do	All dead	40.0
7.	0.6	Do	Do	30.0
8.	0.7	Do	Do	10.0
9.	0.8	Do	Do	All dead
10.	0.9	Do	Do	Do
11.	1.0	Do	Do	Do

The following inferences were drawn from the above table :—

(1) The life activity of the earth-worms decreased with the increase in the percentage of salts.

(2) Sodium chloride was the most toxic. In plants also sodium chloride has got the maximum toxicity.

(3) The following were the percentages of sodium salts when there was complete extinction of life in earth-worms,—

(a) Sodium chloride greater than 0.3%

- (b) Sodium carbonate greater than 0.4%
 (c) Sodium sulphate greater than 0.7%

The second experiment was conducted to investigate the effect of varying moisture percentages on the life of earth-worms. The results of this experiment are presented in table II :—

TABLE II

Showing the effect of different percentages of moisture on the life of earth-worms

%
 Clay = 15.4
 Silt = 18.7
 Sand = 65.6

S. No	Moisture %	Percentage of earth-worms living
1.	10.0	All dead
2.	12.0	Do
3.	15.0	All living
4.	20.0	Do
5.	25.0	Do
6.	30.0	Do
7.	35.0	All dead

A glance at the above table showed that the optimum range of moisture within which the earth-worms could live was from 15.0 % to about 30 % for a sandy loam type of soil.

It was very interesting to observe that even soils containing varying percentages of salines also behaved similarly.

With 0.1% NaCl or 0.2% Na_2CO_3 , the life activity of earth-worms ceased to exist at 10.0% or 35.0% moisture content. The life activity of the earth-worms was, therefore, adversely affected below 15.0% and above 30% moisture content.

(3) The third experiment was designed to study the respective dispersion coefficients of the soils and the mounds formed by the earth-worms in the soils.

Mounds were collected from a number of soils and the dispersion coefficient was determined by dispersion in water only (auto-disintegration). Dispersion coefficient is the ratio between the percentages of clay on auto-disintegration to the total clay on complete dispersion (Puri).⁷ The higher the value of dispersion coefficient, the more impeded the movement of water through that soil would be. Dhawan⁴ concluded from his experiments that the structure of the soil, which was key to all fertility was mainly governed by the dispersion coefficient. Therefore, it was thought desirable to determine this constant in order to study the role of earth-worms in ameliorating the structure of soils.

It is an accepted fact that the alkali soils have the following main characteristics :—

- (i) High dispersion coefficient and low permeability

- (ii) High pH value.
- (iii) High degree of alkalisation.

If by some processes, the degree of dispersion of soils is decreased, there is bound to be more drainage and aeration and the plants will begin to get themselves established. This process would naturally lead to gradual reclamation.

The results of first experiment have revealed the effect of varying percentage of salts on the life activity of earth-worms, from which it was concluded that even at about 0.4% of sodium carbonate (which is the main alkali salt as sodium chloride are neutral salts), the life cycle of the earth-worms existed. This experiment was carried out to see how far the earth-worms affected the dispersion coefficient and exchangeable sodium plus potassium of soils.

Separate samples of the mounds formed by the earth-worms and soil were taken and the dispersion coefficient and exchangeable (Na+K) were determined. Exchangeable (Na+K) was determined by shaking a known quantity of soil by normal ammonium carbonate solution, taking an aliquot portion out of the filtrate, evaporating it to dryness and titrating it with standard HCl (Puri).⁸

The results of the dispersion coefficient and exchangeable (Na+K) are given below :—

TABLE No. I

Showing the comparison of dispersion coefficient and exchangeable Sodium plus Potassium of mounds formed by earth-worms and original soil samples

M—means mounds formed by earth-worms

O—means original sample of the soil.

S. R.	Nomenclature	Dispersion coefficient	Exchangeable Na + K in M.E. per 100 grams soil
1	M	40.9	0.6
2	O	50.4	1.4
3	M	42.7	1.2
4	O	50.0	1.2
5	M	64.4	1.6
6	O	68.2	1.6
7	M	43.4	0.8
8	O	66.3	1.6
9	M	39.3	1.8
10	O	48.6	2.0
11	M	60.8	1.0
12	O	66.2	1.2
13	M	59.0	0.2
14	O	72.3	1.0
15	M	54.9	0.4
16	O	65.6	0.4
17	M	42.9	0.3

S. R.	Nomenclature	Dispersion coefficient	Exchangeable Na+K in M. E. per 100 grams soil
18	O	51.8	0.9
19	M	42.8	0.3
20	O	52.2	1.3
21	M	16.1	0.7
22	O	86.4	4.5
23	M	17.0	1.0
24	O	36.3	1.5
25	M	16.1	2.16
26	O	27.6	0.44
27	M	50.9	0.44
28	O	50.0	0.70
29	M	16.1	0.70
30	O	33.9	0.73
31	M	51.0	1.5
32	O	78.4	2.0
33	M	45.5	0.8
34	O	48.8	1.4
35	M	45.4	0.4
36	O	49.1	0.6
37	M	63.9	0.4
38	O	79.7	0.6
39	M	50.5	0.4
40	O	59.0	0.8
41	M	53.7	0.6
42	O	57.3	1.0
43	M	36.6	0.8
44	O	51.4	1.4
45	M	56.4	1.0
46	O	65.0	0.6
47	M	42.9	1.2
48	O	50.0	0.8
49	M	36.6	1.0
50	O	40.2	0.8
51	M	39.0	0.4
52	O	33.3	0.6
53	M	56.8	0.2
54	O	40.0	0.8
55	M	32.8	2.2
56	O	26.8	2.2

It is concluded from the above results that the mounds formed by the earthworms from the same soil had comparatively less dispersion coefficient and exchangeable (Na + K). This meant better structure as Dhawan and Sharma⁴ concluded from the study of Punjab soils that the dispersion coefficient was the principal governing factor in the determination of the structure of a soil. This would naturally raise the air capacity or in words the aeration of the soil. The low exchangeable (Na + K) of mounds also lent support to this finding.

It is well-known that the alkali soils possess the least aeration due to high percentage of exchangeable sodium. Sufficient aeration is very essential for good

plant growth. If the earth-worms can increase the aeration of the top few inches of the soil, then the rice crop which is considered the most salt tolerant plant for reclamation can get it self safely established. Carbon dioxide is released by the roots of the rice plants and the pH of the carbon dioxide saturated water is about 4. If the rice plants are not established properly in the soil the reclamation process would be obstructed. Therefore, the earth-worms which usually make their appearance during summer rainy season can sufficiently help in the amelioration of the deteriorated soils.

SUMMARY

- (i) The life activity of the earth-worms completely stops at the following concentrations of sodium salts :—
 1. Sodium chloride greater than 0.2%.
 2. Sodium carbonate greater than 0.4%.
 3. Sodium sulphate greater than 0.7%.
- (ii) The life activity of the earth-worms is adversely affected to a great extent below 15.0% and above 30% moisture content.
- (iii) Earth-worms improve the structure of the soils by decreasing their dispersion coefficient and exchangeable (Na+K).
- (iv) Earth-worms help in reclaiming the deteriorated soils.

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ACID, ALKALI AND SALINE SOILS

By

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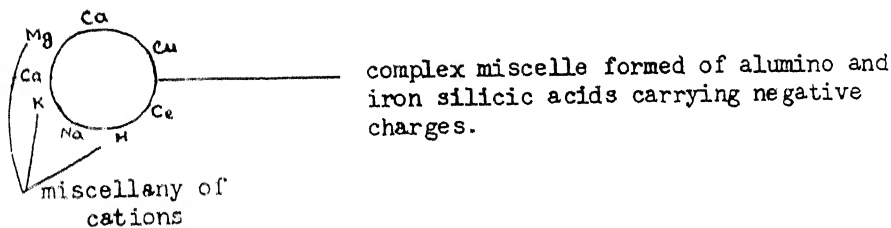
Communicated by Dr. S. P. Mitra

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INTRODUCTION

Acid and saline or alkaline soils occur over wide areas in the world. Acid soils occur in humid and semi-humid regions while saline and alkaline soils are generally found in arid and semi-arid regions.

As is well-known, the colloidal complex is the seat of most of the changes taking place in a soil. The colloidal complex consists mainly of clay and humus. In order to explain the formation of acid and alkali soils as well as the changes taking place in them in the process of reclamation, in a simple manner, the clay complex may be regarded as a salt like compound consisting of a negative and a positive component. The negative radical or micelle is made up of complex, insoluble aluminous and iron silicic acids. A miscellany of cations like calcium, magnesium, sodium, potassium, hydrogen and others form the positive radical. Diagrammatically the clay may be represented as follows :—



The negative charges of the micelle are neutralised by the positive charges of the cations and the clay appears to be neutral. But when suspended in water the cations diffuse into the liquid forming a diffuse double layer in which the cations are not all at the same distance from the micelle. This leaves a net negative charge on the micelle and the picture of the clay particle becomes more complex. The crystal lattice structure of the clay is also there. But the simple diagrammatic representation of the clay is sufficient to explain the changes taking place in acid and alkali soils.

ACID SOILS

During the weathering of rocks salts are formed. In arid and semi-arid regions there is not sufficient rainfall to wash away all the salts. Some or most of them remain in the soil and the cations of these salts dominate the clay

complex. In humid and semi-humid regions, on the other hand, the rainfall is sufficiently high to wash away the salt. With further leaching the cations of the clay become partially replaced by the hydrogen ion of water, particularly when the water is charged with carbon dioxide. Under such conditions neutral or nearly neutral soils may first result. With still further leaching hydrogen obtains a dominant place among the cations of clay and the soil becomes acidic. In mineral soils of pH 4 and less aluminium has been shown to be the most important cation while under natural conditions the humic material also present split off hydrogen ions from the carboxyl groups. So acid soils are formed on account of the leaching to which they are subjected in the humid and semi-humid regions.

While this is perhaps the sequence of changes in the humid and semi-humid temperate regions, where large areas of slightly to moderately acid soils are found, more drastic action takes place in the humid tropics. Under the influence of high temperature (alternate wetting and drying) and heavy rainfall the clay becomes highly acidic and the crystal lattice probably breaks up. Subsequent leaching entails the partial removal of silica from the complex and a matrix consisting of iron and aluminium hydroxides, some silica and a small amount of kaolinitic minerals is left behind. This soil matrix with a porous structure has been called laterite. Since they contain little or no primary clay minerals even the finer fractions of these soil do not exhibit the characteristic properties of typical clays such as base exchange, plasticity, cohesion swelling, etc., to any considerable degree. The amount and intensity of rainfall appears to be more potent in laterite formation than the temperature. In Malabar laterite soils are met with in all regions which receive an annual precipitation of over 100 inches in the south-west monsoon (July to September). In Palghat taluk in the extreme south of the district, which receives only 70—80" of rain per annum distributed in the south-west and north-east monsoon (50—60" in the S. W. and 15—25" in the N. E. monsoons) the soils have not become laterites. They are only lateritic. They are more fertile than the laterites and have a silica sesquioxide also between 1.5 and 2 while the corresponding ratio for the laterites is 1.3 and less. The true laterites have a vermicular structure with sometimes iron concretions. At or near the water table they are very soft and can be readily cut into blocks. These blocks on exposure dry up and become as hard as granite. So laterite is quarried for building material. Under wet cultivation a very fine film of ferric hydroxide is often found floating on the surface of the water. On account of the very high internal area this film has a great capacity to revert soluble phosphates added to the soil. Laterite soils are acidic and are very poor for crop production. They do not contain bases and do not have much power to retain moisture and manures. They revert soluble phosphates into insoluble iron and aluminium phosphates. These soils have to be built up with heavy doses of organic manures.

Acid soils are, therefore, met with in all regions of heavy rainfall. In the tropics, the acid may degenerate into lateritic and laterite soils. Acid soils are not so good for crop production as neutral or nearly neutral soils. A greater variety of crops can also be successfully grown in neutral soils than in acid soils. In highly acid soils plant growth is very poor. The reasons for this infertility are the toxic effect of the hydrogen ion concentration of the soil or of the soil solution on plant roots and the secondary effects brought about by acidity. The secondary effects of acidity are mainly due to a shortage of available calcium and phosphate and to an excess of aluminium and manganese in the soil which are toxic to plants. In the slightly acid soil which occur over large areas

in the world the secondary effects are probably more potent in decreasing crop yield than the direct adverse effect of hydrogen ions. Arnon, (1942) showed that in water culture, plants will grow well between pH 4 and 8 if the secondary effects of the hydrogen ion concentration are eliminated and that plant roots are injured by hydrogen ion only below pH 3 and that above pH 9 they are not able to absorb phosphates and other nutrients.

In Madras large areas of acid soils are found in regions of heavy rainfall in the western and eastern coastal strips and on the hills. These soils are highly deficient in all bases and unlike in other parts of the State the soils have to be given heavy dressings of potassic fertilizers and lime to get good returns. But it is noted that lime beyond a low level does not show any beneficial result in laterite soils. This is probably because the low base exchange capacity of the lateritic and laterite soils prevents the full use of heavy applications of lime.

Acid soils can be improved by changing their reaction to neutrality or near neutrality. This can be accomplished by the application of lime to the soil in the form of calcium carbonate or slaked lime. Then the hydrogen ion of the soil complex are gradually replaced by calcium to give a predominantly calcium soil. The lime requirement of a soil can be estimated by shaking it with a calcium salt solution buffered to pH 6.5 and calculating the quantity of lime required to bring the soil to this pH. Lime is better incorporated into the soil in two or three instalments rather than in one lot. Overliming will not only increase the cost without any purpose but will also bring about harmful effects as it may induce a deficiency of available phosphate, iron, manganese, copper, zinc and boron and prevent the metabolic utilization of these nutrients.

There is another aspect of acid soils which should not be lost sight of. There are certain crops which thrive best under near neutral conditions but which are liable to the attack of diseases at this pH. The potato is a well-known illustration of this. Potato grows best at about pH 7.0 but then it is liable to the attack of potato scab. Between pH 4 and 5 the yield of the crop is not so high but it is free from the disease. Farmers prefer disease free potato and cultivate the crop at the lower pH increasing the acidity of the soil by suitable means wherever necessary. Such a practice is in vogue with certain other crops as well.

SALINE AND ALKALINE SOILS

As opposed to the acid soils of humid regions saline and alkaline soils develop in arid and semi-arid regions. De'Sigmod in 1932 pointed out that there are five stages in the development and subsequent alterations in alkali soils. These are salinisation, alkalinisation, desalinisation, degradation and regradation.

Salinisation refers to the accumulation of salts in a soil and this is the first step in the formation of alkali soils. Saline soils correspond to the "white alkali" soils of Hilgard, the Solonchak of the Russians and the "Uppu Mannu" of Madras. The Regional Salinity Laboratory, Riverside, California, designate soils which contain an excess of soluble salts with pH less than 8.5 and which contain less than 15% of exchangeable sodium as saline soils. In 1947 the workers of the Salinity Laboratory proposed to use as an index of salinity the electrical conductivity of soil solutions which are extracted from soils brought to saturation with distilled water. Soils with a conductivity greater than 4 millimohs per cm at 25°C in their saturation extract are considered as saline. Soils with this conductivity and with more than 15% of exchangeable sodium are regarded as saline.

alkali and soils without much salts (conductivity less than 4 millimohs per cm in the saturation extract) but containing more than 15% of exchangeable sodium are termed alkali soils. The alkali soil of the Americans correspond to the Solonetz of the Russians. However the classification of alkali soils into these groups is arbitrary and does not stand scientific scrutiny. But for the sake of convenience the terms are still used.

In arid and semi-arid regions salt accumulation or the salinisation of a soil may take place in several ways. The salts which are formed in these regions during the weathering of rocks may not be leached away from the locality but may be washed down from elevated places to depressions. There they gradually accumulate to form saline soils. Another mode of formation of saline soils is by the rise of salts from the lower depths to the surface of the soil. This happens when the water table is high, the ground water is rich in salts and evaporation from the soil surface is high in summer. This mode of formation of saline soils may take place even in semi-humid and humid regions if the salt accumulation is greater than leaching. In many of the irrigated areas salinity and alkalinity have arisen in this manner. Salts may accumulate in soils when saline water is used for irrigation and when the land is frequently inundated by sea water.

The evolution of the alkali soil from saline soils is a continuous process. The salts of the saline soil dissolve in the rain or irrigation water. As the salts consist of sodium chloride and sulphate the sodium ions of the solution replace some of the calcium of the soil. The calcium thus removed may or may not be lost from the soil; generally it is lost. As the process goes on over a number of years the soil gradually gets alkalised to contain more than 15 or 25% of exchangeable sodium in the colloidal complex. The soil is now a saline-alkali soil as it contains both soluble salts and exchangeable sodium. This sort of development also occurs in soils in which the salts rise from the ground water or from the lower depths of the profile. Alkali soil not containing much soluble salts may arise when water containing sodium salts is used for irrigation and when the drainage is not defective. Under such conditions sodium gradually enters the exchange complex and an alkali soil is eventually formed without the presence of much soluble salts.

After the formation of a saline-alkali soil, if the water table, by any means, becomes lowered, rain or irrigation water washes down the salts. As long as sufficient salts remain their electrolytic effect keeps the soil flocculated and the permeability of the soil remains good. When however, the soil concentration becomes low the soil containing more than 25% of exchangeable sodium loses its water stability and becomes dispersed. The dispersion of the clay and humus is hastened and aided by the partial hydrolysis of the soda clay forming sodium hydroxide and eventually sodium carbonate. The sodium carbonate in the soil solution at the top may dissolve some humus and when the solution dries up dark patches are left behind. Such soils have been called "black alkali" soils by Hilgard. The sodium carbonate found in such soils may also arise by the interaction between sodium sulphate and the calcium carbonate of the soil since the solubility of CaCO_3 is greater in sodium sulphate solution than in water. $\text{Na}_2\text{SO}_4 + \text{CaCO}_3 = \text{Na}_2\text{CO}_3 + \text{CaSO}_4$. The second stage in the washing out of the salts is when the dispersed clay and humus move down the profile and get deposited in the B horizon when the leaching proceeds and the exchangeable sodium are removed from the top soil the upper horizons may become neutral or even slightly acidic while the lower depths are alkaline. Such soils have been called Solonetz in the early stages and Solod in the later stages of development by Russians.

In Madras State saline and alkali soils occur in various parts in pockets as well as over large areas. A survey of the extent and nature of such soils has not been made although long overdue. The saline and alkali soils in Madras have developed from natural state of affairs such as topography—arid and semi-arid conditions, inundation by sea water, etc. Unlike in other parts of India such as in the Nira valley in Bombay and the Irwin canal area in Mysore irrigation in Madras has not led to the development of alkalinity. This is because before any irrigation project is taken up the Madras Government have undertaken the soil survey of the ayacut area to find out the suitability of the soils and water for irrigation. Only where damage is not likely or where the damage to the soil likely to arise on account of irrigation can be countered by simple preventive measures are the projects executed. For example the Mettur project (old Tanjore Delta), the lower Bhavani project, etc. were recommended as suitable and the Bhairavanitippa project was recommended with certain precautions and adjustments. Where there was any doubt as to how the soils would behave on irrigation experiments were undertaken to clarify the issue. Thus before the Tungabadra project was executed light and heavy irrigation experiments were conducted on the typical soils of the tract at Siruguppa. The Gandikota and Gundalkama projects were declared unsuitable either on account of the nature of the soil or the quality of the irrigation water.

Gypsum is found in many soils including alkali soils. In Madras soils, especially in black soils of the regur type, it generally occurs in the third or fourth foot and it is often associated with a high concentration of sodium sulphate and chloride. The occurrence of such gypsaceous layers in soils has not yet been satisfactorily explained. It is probable that in the black soils of Madras the sulphate of the salts including gypsum is obtained by the oxidation of the sulphur or iron pyrites or of sulphur bearing feldspathoid minerals.

EFFECT OF SALINE AND ALKALINE SOILS ON PLANT GROWTH

It is well-known that plant growth is adversely affected in saline and alkaline soils and that under high salinity or alkalinity no plant will grow.

EFFECT OF SALTS AND THEIR IONS

With regard to soluble salts in soils two kinds of effects are possible ; (1) the general effect of the salts, and (2) the specific effect of individual cations and anions. The general effect of the salts is due mainly to the raising of the osmotic pressure of the soil solution round the root hairs. Magistad (1947) obtained a linear relationship between the osmotic pressure of soil solution and the reduction in the yield of the crop. The Regional Salinity Laboratory, U. S. A., (1947), has worked out a formula to find out whether a soil is suitable for crop production or not. The soil is mixed with small quantities of water and worked up to its sticky point. A portion of the liquid is then removed by suction. If it contains less than 3000 p.p.m. of salt or has a specific conductivity of 4 millimohs or less per cm the soil is regarded as suitable for the cultivation of most crops. If the solution contains between 3000 and 5000 p.p.m. of salts (specific conductivity between 4 and 8 millimohs per cm) crop yield decreases in proportion to the salt content and only the salt tolerant crops will do fairly well at the higher concentration. With 10,000 p.p.m. of salt in the soil solution (conductivity about 15 millimohs per cm) crop production in the soil will be useless. The chief cause of the harmful effect of high osmotic pressure is the inability of the plants to

obtain water for its use. So soils having high salinity require more frequent irrigation than those containing little salt.

As regards the specific effect of the salts or their ions it has been shown that the borate ion is the most harmful and soil solution and irrigation water containing 2 p.p.m. or more of borate is highly toxic to plants. Next in the degree of toxicity are the carbonate and the bicarbonate ions. Carbonate has a highly corrosive action on root hairs and the tender roots. The bicarbonate ion as such is probably not very harmful but it can easily be converted into carbonate and is therefore potentially harmful (Wilcox *et al.*, 1954). Chloride and sulphate are, however, the ions most commonly found in saline and alkaline soils and of these most plants are more tolerant of the sulphate than the chloride ion. The plants most sensitive to chloride are the citrus family. It is, however, difficult to isolate the effect of the anion from that of the accompanying cation and so the conclusions about the effect of the ions should be viewed with caution. But it is believed that sodium ions (in solution) as such are not any more harmful than other cations. The observed bad effects of alkaline soils and attributed to sodium are probably due to the non-availability of calcium and other nutrients.

ADSORBED CATIONS

Of the absorbed cations in saline and alkaline soils the most important is sodium. When this is present in excess of 25% of the exchange capacity in the soil, it has been shown to have highly toxic effect on plants. Bower and Wedleigh (1948) found crop production in a soil to decrease with increasing amounts of exchangeable sodium reaching a minimum when three-fourths of the soil complex is dominated by this cation. The same authors (1950) found exchangeable sodium to be more harmful than an equivalent amount in solution. The harmful effect of exchangeable sodium is due not only to its direct toxic effect but also to the fact that its presence in large quantities renders calcium unavailable and brings about an unfavourable physical condition of the soil. Sodium hydroxide and carbonate resulting from the partial hydrolysis of sodium soil also enhances the pH of the soil with the consequent unavailability of phosphate and other nutrients to the plant. Root development of plants in a soil saturated with sodium is practically nil.

Magnesium is another metallic cation which has been found to be harmful when present in excess in the exchange complex. Vlamis, (1949) found that lettuce plants made no growth in a soil saturated with magnesium. Magnesium soil undergoes dispersion like sodium soil (Usov, 1937.) Vlamis, however, showed that if 20% of the exchange complex of a soil consists of calcium and the rest of magnesium the soil was not toxic to lettuce. The harmful effect of excessive magnesium is probably due to the non-availability of calcium and the bad physical condition it induces.

CONTROL OF SALINITY

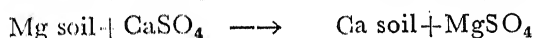
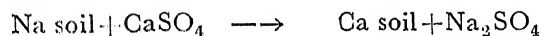
If a soil contains only a fair amount of soluble salts the salinity can be controlled so that crop production is made possible. The salt concentration in the soil solution should be reduced so that osmotic effects are precluded. The water used for irrigation should contain as little of soluble salts as possible. The soil should be flooded to wash out the salts before sowing seeds. Again, as young seedlings are more sensitive to salt concentration than well-established plants heavy irrigations should be given in the early stages of the crop to dilute the salt concentration. Evaporation of water from the soil surface should be reduced to the minimum and for this a mulch is effective. It is most important

to have an effective drainage system so that the salts may be washed down into the sub-soil below that root zone. Of the three types of drainage systems in use, namely the open ditch drain, the tile drain and the pumping system, only the open ditch system is practicable under the conditions in India. The pumping system of lowering the water table, however, has the advantage that the water table can be lowered to any desired depth and that the water pumped out may, if it is not saline, be used as irrigation water lower down the terrain after mixing with good water.

McGeorge and Wharton, (1936) has developed a ridge method of cultivation for saline soils in the Salt River Valley in Arizona. In the method the land is thrown up into ridges and water is let in between the ridges. Salts accumulate at the top of the ridges leaving the sides and furrows with less salt at each irrigation. Lettuce was successfully grown on the sides of the ridges.

RECLAMATION OF SALINE AND ALKALI SOILS

The reclamation of saline and alkaline soils means their conversion into normal soils fit for the cultivation of crops. The improvement can be effected by removing the causes of infertility, namely, the high content of soluble salts and/or the high amount of exchangeable sodium and sometimes magnesium present in the soil. The soluble salts can probably be removed by leaching with water and the exchangeable sodium and magnesium can be replaced by calcium with the help of a soil ameliorant like gypsum :—



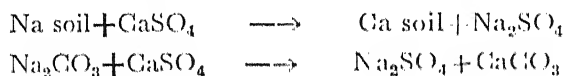
The salts present and those formed should be dissolved and removed in the drainage water. So the most imperative requirements for the reclamation of saline and alkaline soils are a supply of good water and an efficient system of drainage. The water table in the soil should be lowered so that the percolating waters carrying the dissolved salts are removed beyond the root zone of the plants.

Leaching, *i.e.*, the flooding of the soil with water and the removal of the salts in the drainage water, has been employed in the reclamation of saline and alkaline soils by Kelly and others, especially when the soil contains reserves of calcium carbonate. In purely saline soils each leaching will lower the salt content. Calcium carbonate present in the soil will, to some extent, dissolve in the salt solution and the dissolved calcium will replace any sodium that may be present in the soil complex. When the salt content becomes low enough by leaching, green manure crops, preferably legumes, may be grown and incorporated into the soil. The carbon dioxide liberated by the crop roots and that formed during the decomposition of the plant residues will bring into solution sufficient calcium carbonate from the soil and convert it into a calcium soil. The incorporation of the organic matter also improves the physical condition of the soil and it is now fit for crop production.

In a saline-alkali soil also leaching will bring about some improvement of the soil. As long as there is sufficient amount of salts in the soil the permeability will be good. But when the major portion of the salts are washed out the sodium soil gets dispersed. The permeability falls considerably and the rate of leaching becomes so slow that no perceptible improvement will be noted for

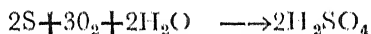
years. Under such conditions a soil ameliorant should be employed to bring about the reclamation. The materials used for the purpose are gypsum, sulphur, ferrous and aluminium sulphates, sulphuric acid, liquid sulphur dioxide, bulky organic manures, etc. The purpose in adding these ameliorants is to lower the pH of the soil, to improve its permeability and to convert the sodium soil into a predominantly calcium soil. These materials except gypsum do not contain calcium and there should be sufficient calcium carbonate in the soil for them to be fully effective. Calcium carbonate is practically insoluble and inactive in alkali soils above pH 8.5. By lowering the pH calcium carbonate reserve of the soil is brought into solution and the soluble calcium replaces exchange sodium to give a calcium soil or a normal soil.

Gypsum is calcium sulphate which occurs abundantly in nature in many parts of the world. It reacts with the sodium complex of alkali soils and converts it into the desired calcium soil. It also reacts with any sodium carbonate, that may be present and changes it into the less injurious sodium sulphate :—

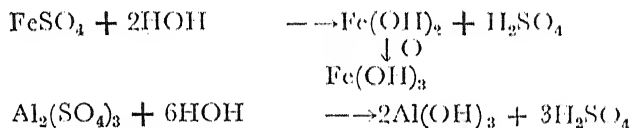


In both the reactions sodium sulphate is formed. The solubility of gypsum in water is low; it is still less so in sodium sulphate solution. So in order that gypsum should be an effective agent in reclamation, the soil should be frequently flooded and drained. Shawarabi and Abdel-Bar, (1954) have formulated a simple method of estimating the amount of gypsum to be added to reclaim alkali soils. 10 gms of the air-dry soil are titrated with increasing amount of N/50 sulphuric acid to reduce the pH to 8.0—8.3. Each cubic centimeter of N/50 sulphuric acid indicates the addition of 1 ton of gypsum to the soil to a depth of 20 cm per acre.

Sulphur incorporated into alkali soils is slowly oxidized to sulphuric acid by sulphur oxidizing bacteria. The acid neutralizes any sodium carbonate that may be present and lowers the pH of the soil. The acid also reacts with the calcium carbonate of the soil to give calcium sulphate which replaces the sodium of the soil :—



Ferrous and aluminium sulphates hydrolyze in water to form sulphuric acid and the corresponding hydroxides which later become inert in the soil :—



The sulphuric acid brings about the reclamation of alkali soil as under sulphur.

Liquid sulphur dioxide may be dissolved in the irrigation water when it forms sulphurous acid. This is easily oxidized to sulphuric acid. The cost of the chemical however, is the chief factor against its use.

Farmyard manure, composts, and green manures are also useful in reclaiming alkali soils. Molasses is claimed by Dhar (1936) to be, very suitable for the

purpose. These organic substances produce acids during their decomposition and reduce the pH of the soil. They also open up the soil. The carbon dioxide resulting from their decomposition bring calcium carbonate into solution as calcium bicarbonate and help in replacing exchangeable sodium with calcium. However the effect of the organic materials is slow and spectacular results cannot be obtained as with chemical ameliorants.

The most commonly used agents for the reclamation of alkali soils are gypsum, sulphur and organic manures. In India sulphur does not occur in nature in large quantities and has to be imported. So it is costly and is not generally employed. Gypsum deposits are however found in many parts of India. The material is cheap and is used for the improvement of alkali soils.

It is fortunate that, under natural conditions, it is not necessary to remove the soluble salts and/or the exchangeable sodium of the soil completely before plants can be grown on them. After some improvement when the soil can support it, a salt tolerant green manure crop, preferably a legume may be grown. The plant roots help to improve the permeability of the soil by forming cracks through which water will move downwards. The carbon dioxide let off by the roots will reduce the alkalinity. The green manure crop should then be ploughed in. This will open up the soil. The carbon dioxide of the decomposing organic material will further improve the alkaline soil. The soil is now good enough to grow normal crops. Salt tolerant varieties of paddy such as S.R.B. 26 may be successfully cultivated. The drainage system should be kept efficient to maintain the improvement already effected.

In many parts of the world reclaimed alkali soils have deteriorated. This was because the drainage became defective and the re-accumulation of salts and the re-alkalinisation of the soil took place.

The methods of reclamation described above have assumed that sufficient water is availing for the flooding of the soil. There are several areas in all parts of the world where water is scarce. In such regions the reclamation of alkali soils has been regarded as almost impossible. In Madras, however, attempts have been made with some success to improve alkali soils under dry conditions (in places where water is scarce) by using the water received as rain.

RECLAMATION EXPERIMENTS IN MADRAS

Several alkali land reclamation experiments have been successfully carried out by the Agricultural Department of Madras. The mode of attack is based on the texture of the soil. In heavy clay soils gypsum at 10 tons and sulphur at 1 and 2 tons per acre have been found to be very effective. A piece of barren land at Mettumarudur in Tiruchirapalli district where not even grass would grow was converted into excellent paddy land. One year after the start of the experiment the paddy crop gave a yield of 1,000 lb per acre. After a second green manure crop was ploughed in the yield was raised to 3000 lb per acre in the gypsum plots while the control plots remained as barren as before. Effective open trench drainage was maintained throughout the experiment.

In a sandy soil at Pattukottai containing about 10% of the finer fractions, with low soluble salts but with a very high degree of alkalisation gypsum at 1 and 2 tons was found ineffective in improving the soil. But, through reclamation was obtained with green leaf at 5,000 to 7000 lb per acre and with molasses at 2½ to 5 tons. Gypsum probably rendered the light soil highly porous for the cultivation of paddy.

In the reclamation of alkali soils under dry conditions (when water is scarce) at Guntur the treatments tried were bunding, application of heavy doses of cattle manure (40 tons per acre) and soil mulching. The water received as rain was used for washing down the salts. A marked decrease in the salt content was noted in all the treatments the maximum improvement being in cattle manure plots.

Improvement of sea inundated soils could be effected by washing away the salts with good water provided the drainage is good and bulky organic manures are incorporated when reserves of calcium carbonate are available. Gypsum may be added when calcium in the soil is low.

ACKNOWLEDGMENT

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ROLE OF ROCK PHOSPHATE, BASIC SLAG AND CALCIUM CARBONATE MIXED WITH SUNN-HEMP (*CROTOLARIA JUNCEA*) AS ORGANIC MATTER IN RECLAMATION OF ALKALI SOIL

By

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(Received on 17th December, 1954)

Alkali soil occurs in hot and arid and semi-arid regions of the world. It is one of the most important resources of the world that can be effectively utilized to meet the food problem of different countries. Alkali soil is expanding in areas where new and artificial methods of irrigation have been introduced. It has often been found that alkali salts begin to spring up *de novo* where none was present.

Earlier workers attributed the toxicity of this soil to the presence of soluble salts and the general opinion was that their removal through leaching was possible. This method did not prove helpful and no permanent cure was obtained. Bertholet, Mondesir and Hilgard pointed out that the toxicity was due to the presence of free alkali like sodium carbonate. Lipman¹ suggested the use of sulphuric acid and sulphur in reclaiming these soils. Hibbard² working on the suggestion of Lipman found that gypsum could be used in neutralizing the alkalinity caused by sodium carbonate in the soil. Gedroiz, Hissink, de Sigmond, Joffe and Kelley definitely believed that normal soil consists mainly of calcium clay but under adverse condition excess of sodium salt react with clay portion and produces what is known as sodium clay, which is the main cause of the formation of alkali soil. For any permanent cure the first essential factor is to convert the sodium clay into calcium clay with the help of any calcium rich compound. Gypsum, calcium carbonate, calcium chloride,³ sulphur and aluminium sulphate have been used in reclaiming alkali soils.

Dhar⁴ writes "Unlike the soils of temperate countries the Indian soil is deficient in organic matter and in total nitrogen. This significant fact must be taken into account in studying the problem of alkali soil reclamation in our country. Unless an attempt is made to raise the carbon and nitrogen status of soil, mere addition of inorganic chemicals to lower the pH values of soil will not be of much use in reclamation process."

Following the above principles of reclamation, organic matter mixed with different amendments have been tried for the reclamation of alkali soils.

EXPERIMENTAL

Alkali soil used in these experiments was obtained from Soraon, a place approximately 13 miles from Allahabad. It was dried and sieved through 100 mesh. Sunn-hemp of three months old green sample with nodules was dried

and chopped first with a hand implement and finally cut to small pieces with a mechanical chopper.

200 grams of alkali soil was taken in enamelled dishes and were mixed with sunn-hemp in two dozes (13 and 26 grams). Amendments like rock phosphate, basic slag and calcium carbonate were also used in two dozes (1% and 2%). These experiments were continued for seven months during which period they were watered with distilled water and stirred up once or twice a week. The estimation of exchangeable calcium was done by Hissink's method,⁶ pH was determined colorimetrically⁶ in 1: 2.5 extract of the soil in normal potassium chloride solution and carbon was estimated by the method of Robinson, Meleaus and Williams.⁷

RESULTS

TABLE 1

Composition of oven-dry soil

pH	10.0
Total carbon	0.1350%
Total nitrogen	0.0353%
CaO	0.1064%
P ₂ O ₅	0.1068%
Exchangeable Ca	3.5720 m.e. %

TABLE 2

Percentage composition of Sunn-hemp

Total carbon	37.701
Total nitrogen	1.232
CaO	2.100
MgO	0.160
P ₂ O ₅	1.518

TABLE 3

Analysis of Rock phosphate and Basic slag on oven-dry basis

	Rock phosphate	Basic slag
	%	%
P ₂ O ₅	19.56	7.90
CaO	11.62	32.20
MgO	0.71	2.55
Carbonate	5.31	23.82

TABLE 4

200 grams Alkali soil + 13 grams Sunn-hemp

Amendment	Doze of amendment (%)	Carbon (%)	2 months		4 months		7 months	
			pH	Ex. Ca. m.e. %	pH	Ex. Ca. m.e. %	pH	Ex. Ca. m.e. %
1. Control	...	2.47	9.8	4.20	9.7	4.31	9.4	5.22
2. Calcium carbonate	1	2.47	9.7	5.60	9.4	6.22	8.7	6.50
3. Basic slag	1	2.47	9.6	5.65	9.3	6.47	8.7	6.90
4. Rock phosphate	1	2.47	9.5	5.80	9.2	6.35	8.5	7.40
5. Calcium carbonate	2	2.47	9.7	5.74	9.5	7.53	8.8	7.82
6. Basic slag	2	2.47	9.6	5.84	9.2	7.65	8.7	8.00
7. Rock phosphate	2	2.47	9.4	6.25	9.0	8.32	8.2	8.74

TABLE 5

200 grams Alkali soil + 26 grams Sunn-hemp

Amendment	Doze of amendment %	Carbon %	2 months		4 months		7 months	
			pH	Ex. Ca. m.e. %	pH	Ex. Ca. m.e. %	pH	Ex. Ca. m.e. %
1. Control	...	4.59	9.7	4.50	9.6	5.32	9.2	5.92
2. Calcium carbonate	1	4.59	9.6	5.70	9.4	6.21	8.6	6.75
3. Basic slag	1	4.59	9.5	5.75	9.3	6.37	8.6	6.90
4. Rock phosphate	1	4.59	9.5	5.95	9.1	7.03	8.4	7.82
5. Calcium carbonate	2	4.59	9.6	5.87	9.4	7.50	8.7	8.33
6. Basic slag	2	4.59	9.5	5.95	9.2	7.81	8.6	8.52
7. Rock phosphate	2	4.59	9.4	6.54	8.7	8.62	7.9	9.31

TABLE 6

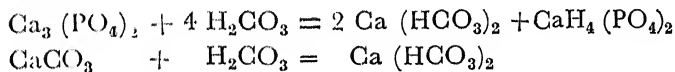
Carbon oxidation during reclamation

Amendment	Doze of amendment %	Sunn-hemp (grams)	Carbon %	% carbon left		
				2 months	4 months	7 months
1. Control	...	13	2.47	1.926	1.820	1.740
2. Control	...	26	4.59	3.246	3.010	2.800
3. Calcium carbonate	1	13	2.47	1.643	1.420	1.210
4. Basic slag	1	13	2.47	1.730	1.520	1.320
5. Rock phosphate	1	13	2.47	1.850	1.648	1.467
6. Calcium carbonate	1	26	4.59	2.671	2.350	2.040
7. Basic slag	1	26	4.59	2.854	2.640	2.420
8. Rock phosphate	1	26	4.59	3.160	2.870	2.593
9. Calcium carbonate	2	13	2.47	1.579	1.311	1.052
10. Basic slag	2	13	2.47	1.676	1.401	1.160
11. Rock phosphate	2	13	2.47	1.760	1.558	1.351
12. Calcium carbonate	2	26	4.59	2.471	2.010	1.610
13. Basic slag	2	26	4.59	2.617	2.210	1.810
14. Rock phosphate	2	26	4.59	3.064	2.770	2.470

DISCUSSION

The foregoing results show that the highest fall of pH and highest increase in exchangeable calcium take place in samples treated with rock phosphate in conjunction with sunn-hemp. Basic slag is slightly better than calcium carbonate but definitely worse than rock phosphate in decreasing the pH and increasing the exchangeable calcium status of the soil.

The role of these sparingly soluble calcium rich substances in reclamation of alkali soil is explained by the fact that they supply calcium ion by the action of carbon dioxide produced during the decomposition of organic matter. The calcium ion removes the sodium ion from the exchange complex leading to the increase in exchangeable calcium.



Russell⁹ and Magistad¹⁰ claimed that carbon dioxide produced during the decomposition of organic matter in soil dissolves in water to form carbonic acid which increases the solubility of calcium carbonate in the soil.

The usefulness of rock phosphate is due to the fact that it does not contain so much carbonate as in calcium carbonate or basic slag. This may be the reason for its improving alkali soils better than any other amendment used in these experiments. The oxidation of organic matter was highest in the first sixty days after which it slowed down. Maximum oxidation was observed in the samples treated with calcium carbonate. Rock phosphate treated samples underwent the least amount of oxidation. This agrees well with the well established law that alkaline material enhances the oxidation of any system to which it is added.

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STUDY ON THE CHARACTERISTICS OF ALKALI SOIL PROFILE

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There are vast tracts of alkali lands in U.S.A., U.S.S.R., Hungary, India and other parts of the world. Hilgard¹ in America, Gedroiz² in Russia, Sigmond³ in Hungary and Hissink⁴ in Holland have contributed to an understanding of alkali soils. In India Voelcker,⁵ Hoon and Mehta⁶, Puri,⁷ Dhar and co-workers⁸ and Leather⁹ have done a lot of work on this problem. Leather¹⁰ in his report on "Investigation on Usar Land in U.P." has also mentioned about the occurrence of alkali patches in fertile wheat and jawar fields of Aligarh and Mathura districts. "The Usar Land Reclamation Committee, United Provinces"¹¹ has also mentioned about the occurrence of usar patches which are associated with the fine textured alluvium of Ganges river.

In this paper we have studied the morphological as well physico-chemical properties of alkali soil profile from Soraon, near Allahabad. The morphological study, mechanical analysis, base exchange capacity, natural moisture, dispersion factor and the chemical analysis were carried out systematically.

METHODS AND MATERIAL

After digging the soil profile, the soil was collected from different layers in gunny bags and were brought to the laboratory, and then was spread in thin layer. The soil was stirred frequently and was completely air-dried. The clods were then crushed and the soil was sieved through a 2 mm sieve to remove the stones, gravels and extraneous organic matter.

Mechanical analysis was done by the pipette method described by Piper.¹² Base exchange capacity was done according to the method of Piper.¹³ Exchangeable calcium and magnesium were estimated by Hissink's¹⁴ method. In every case the pH was determined by Beckman pH meter. Water soluble salts were estimated by the method described by Piper.¹⁵ Natural moisture was estimated as follows :—

Soon after the profile samples were taken, a weighed amount of samples from each layer were dried at 100°C to constant weight and the loss was reported as natural moisture. Dispersion factor was estimated according to the method of Puri.¹⁶ The complete chemical analysis of each layer was done by the method of Knowles and Watkin.¹⁷

RESULTS AND DISCUSSION

TABLE 1

Morphological study

Depth in inches	Morphological characteristics
0—6	Whitish grey, friable in constitution, structureless, show efflorescence on the surface, no plant root visible, pink colour with phenolphthalein, gave the pH range between 10—11 with universal indicator.
6—12	Dark grey with yellow white patches, clayey, compact, tenacious, easily rupturable, kankar present, no definite structure, pink colour with phenolphthalein, pH ranges with universal indicator between 10—11.
12—24	Dark grey without any patch, compact, tenacious, clayey, large amount of kankar present, structureless, pink colour with phenolphthalein, pH ranges with universal indicator 9—10.
24—36	Brownish grey, small patches, less compact, small concretion, pink colour with phenolphthalein, pH ranges with universal indicator between 9—10.
36—48	Somewhat as above, more moist than above, pink colour with phenolphthalein, pH with universal indicator 9—10.
48—60	Light yellow with brownish and black spots, pink colour with phenolphthalein, pH with universal indicator varies between 9—10.
60—72	Light yellow, less compact, pink colour with phenolphthalein, pH ranges with universal indicator between 9—10.

Mechanical composition.—In usar soil permeability of water is low and soils set hard when dry. It is clear that it is the dispersed phase of the soil, which due to the cementing action of clay colloids, is responsible for this phenomenon. Determination of silt and clay were made from the soil samples to elucidate their function in characterisation of alkali soils and the results have been recorded in table No. 2.

TABLE 2

Depth in inches	Clay %	Silt %	Total %
0—6	14.20	40.30	54.50
6—12	16.21	58.01	74.22
12—24	17.50	61.86	79.36
24—36	16.02	49.70	65.72
36—48	12.50	46.65	59.15
48—60	11.91	48.62	60.53
60—72	12.40	44.15	56.55

It is clear from the above table that the percentage of silt and clay is highest in second and third layer. This may be attributed to the following facts :—

1. Most of the kankars consist of particles below 0.002 mm which add to the clay content.
2. Eluviation of clay from neighbouring areas to the alkaline land.

3. Low lying areas contain large amount of clay leachings from higher land.

4. Vertical leaching of clay and clay content in second and third layer. This generally takes place due to the mobile dispersive action of clay.

The base exchange capacity, exchangeable Ca and exchangeable Mg and pH have been recorded in table No. 3.

TABLE 3.

Depth in inches	Base exchange capacity m.e. %	Exchangeable Ca m.e. %	Exchangeable Mg m.e. %	pH
0—6	6.94	2.06	1.15	10.3
6—12	9.21	3.78	1.02	10.1
12—24	13.50	6.73	1.16	10.0
24—36	12.46	6.38	1.40	9.8
36—48	10.67	6.34	1.32	9.6
48—60	11.74	6.42	1.50	9.4
60—72	11.35	6.83	1.52	9.2

From the data in table No.3 it is clear that the base exchange capacity is highest in the layer of soil between 1'—2', which may be due to the influence of clay colloids which are also present in sufficiently high concentration in the layer mentioned. It is also well-known that base exchange phenomenon is, to a greater extent, influenced by the presence of clay colloids. The calcium associated with Ca soils are responsible for the flocculation of soil colloids in fertile fields. But on the other hand, as our experimental observations show, the concentration of divalents *i.e.*, Ca and Mg is highest in lower layers. This may be attributed to the fact that the divalents might have been leached down in the lower layers. The presence of monovalents is responsible for the deterioration of soil structure. Magnesium is found in wide variation in each layer.

Total water solubles, natural moisture and dispersion factor have been determined and the results have been recorded in table No. 4.

TABLE 4.

Depth in inches	Total water solubles %	Natural moisture %	Dispersion factor
0—6	0.324	12.93	10.20
6—12	0.312	18.61	12.31
12—24	0.296	18.59	12.53
24—36	0.187	19.53	11.70
36—48	0.165	20.47	11.98
48—60	0.163	21.30	10.76
60—72	0.156	21.76	10.65

From the above table it is clear that the salts show the tendency to migrate up, the decrease being gradual with depth. This may be due to the lateral movement of salts from the neighbouring fields. These salts then leach down or migrate up in the wet and dry weather respectively. This is generally the

common phenomenon in all usar soils. Again it will be seen from the foregoing table that the natural moisture is higher in lower layer which may be due to the high clay colloid content of the usar profile in lower layers. The lower layer might be rich in Na saturated absorption complex, and consequently have a high imbibitional and swelling capacity on being moist and hence the natural moisture is higher in lower layers than that of upper ones. Dispersion factor is also higher in lower layers which may also be attributed to the above mentioned facts

The results of chemical analysis have been recorded in table No. 5.

TABLE 5

Depth in inches	Moisture %	Loss on ignition %	HCl insoluble %	Fe ₂ O ₃ %	CaO %	MgO %	P ₂ O ₅ %	K ₂ O %
0—6	1.37	3.18	83.64	1.20	1.68	1.52	0.178	0.685
6—12	1.52	3.02	63.94	2.16	1.74	1.63	0.214	0.650
12—24	1.35	3.78	56.67	2.48	1.46	1.21	0.105	0.522
24—36	1.42	3.92	48.33	2.44	1.87	0.98	0.046	0.470
36—48	1.51	3.20	53.13	2.52	1.79	1.02	0.074	0.439
48—60	1.32	3.15	47.88	2.72	1.92	0.63	0.071	0.501
60—72	1.31	2.87	63.94	2.80	1.34	0.76	0.067	0.412

It is clear from the table No. 5 that as we go up from lower to upper ones the P₂O₅, K₂O and MgO goes on increasing. Silica varies markedly in each layer. On the other hand CaO and Fe₂O₃ goes on increasing from upper layers to lower layers. From column No. 3 of the table No. 5 it can be concluded that the organic matter is somewhat higher in third and fourth layers in comparison to other layers. This may be due to the presence of some plant residues and other organic matter present in these two layers (3rd and 4th). In upper layer the organic matter is also in lower concentration. It seems that due to the action of light and high temperature in tropical countries, like ours, and also due to the presence of alkali salts in higher concentrations in the upper layer, which help oxidation, the organic matter might have been decomposed and that is why the percentage of organic matter is less in the uppermost layer. It has been reported by Dhar and co-workers that light facilitates oxidation of organic matter. It is well-known that alkali also favours oxidation of organic matter.

SUMMARY

The morphological, physico-chemical and mechanical analysis of alkali soil profile (0—72 inches in depth) brought from Soraon, Allahabad, have been studied systematically. The results show great variation in their morphological, mechanical and chemical characteristics. The chemical analysis of different layers shows that the upper has a low organic matter content and rich in alkali salts. This has been attributed to the fact that these alkali salts facilitate in the decomposition of organic matter. Moreover high intensity of sunlight, in the upper most layer, helps the oxidation of organic matter.

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EFFECT OF SUNN-HEMP AND ALFALFA ON THE RETARDATION OF NITROGEN LOSS, WHEN AMMONIUM SULPHATE AND SODIUM NITRATE ARE ADDED TO ALKALI SOIL

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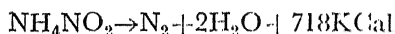
Of the three principal fertilizing elements required by the plants—nitrogen, phosphorus and potassium,—nitrogen is the most important element. But inorganic compounds like ammonium salts and nitrates do not remain for a long time in the soil without undergoing serious losses, due to the elusive nature of nitrogen. Lohnis and Fred¹ have reported that in field experiment of four years duration, the following plant food materials were taken off in the manured crop :—

Nitrogen%	Phosphorus%	Potassium%
7.8	10.1—75.6	22.4—85.1

Thus it is clear that out of the three nutrients, the recovery of nitrogen is the lowest, *i.e.*, about 40—50% at the most, whereas the recovery of phosphorus and potassium is as high as 70—80%. Russell and Richards² and others have also shown that when the conditions for oxidation are favourable, the loss of nitrogen takes place in gaseous state. Lipman and Blair³ also observed losses of nitrogen in their experiments.

While dealing with the losses of nitrogen from the soil, Russell⁴ has stressed that losses are due to leaching and formation of volatile compounds, which liberate nitrogen. Willis and Sturgis⁵ have shown that nitrogen can be lost to the atmosphere as ammonia and it can be of considerable importance in alkali soil, under hot and wet conditions, such as occur in many paddy rice fields. Dhar⁶ has explained the loss of nitrogen on chemical and photo-chemical basis. This loss of nitrogen has been explained by Dhar as follows :—

Ammonia while being oxidized is converted into nitrite during the first stage and thus along with free ammonia ions present, form ammonium nitrite which readily decomposes on account of its unstable nature into nitrogen and water.



The photo-chemical view of nitrification and nitrogen loss put forward by Dhar has been supported by many workers from different parts of the world.

METHOD AND MATERIALS

The total carbon was estimated by the method of Robinson, Mclean and Williams.⁷ Total nitrogen was estimated by the Kjeldahl method as modified by Treadwell and Hall,⁸ using salicylic acid for the reduction of nitrites and nitrates.

200 grams of well powdered alkali soil (from Soraon, Allahabad) after having been passed through 80 mesh sieve were taken in white enamelled dishes of seven inches diameter. 0.1% and 0.25% nitrogen as ammonium sulphate and 0.1% and 0.25% nitrogen as sodium nitrate was added in different sets. 0.5% carbon was added either in the form of sunn-hemp or alfalfa. 20% moisture in the form of distilled water was introduced in every dish. These dishes were exposed to the artificial light from a 500 watt electric bulb hung over a distance of about two feet. The contents of the dishes were stirred on alternate days to help aeration and nitrification. The moisture content was maintained at about 20% throughout the duration of experiment. After an interval of 60 days and 120 days samples were taken out from each dish, oven-dried and analysed for total carbon and nitrogen.

RESULTS

TABLE 1

200 gms soil + 0.1% N as $(\text{NH}_4)_2 \text{SO}_4$

Period of exposure in days	Total carbon %	Total nitrogen %	Nitrogen loss %	
				lbs per acre
0	0.1136	0.13178	...	...
60	0.1070	0.08337	48.4	1084.16
120	0.0985	0.07258	59.4	1326.00

TABLE 2

200 gms soil + 0.1% N as $(\text{NH}_4)_2 \text{SO}_4$ + 0.5% C as Sunn-hemp

0	0.5969	0.15185	...	...
60	0.4641	0.11146	40.4	904.96
120	0.4248	0.10315	48.7	1090.88

TABLE 3

200 gms soil + 0.1% N as $(\text{NH}_4)_2 \text{SO}_4$ + 0.5% C as Alfalfa

0	0.6034	0.15405	...	...
60	0.5033	0.11176	42.3	947.52
120	0.4749	0.10344	50.6	1133.44

TABLE 4

200 gm soil + 0.25% N as $(\text{NH}_4)_2 \text{SO}_4$

0	0.1122	0.27920	...	...
60	0.1061	0.17021	43.6	2441.60
120	0.0996	0.14820	52.4	2934.40

TABLE 5

200 gms soil + 0.25% N as $(\text{NH}_4)_2 \text{SO}_4$ + 0.5% C as Sunn-hemp

0	0.5929	0.29576	...	...
60	0.4726	0.20525	36.2	2027.20
120	0.4346	0.18374	44.8	2508.80

TABLE 6

200 gms soil + 0.25% N as $(\text{NH}_4)_2 \text{SO}_4$ + 0.5% C as Alfalfa

0	0.5992	0.30031	...	...
60	0.5105	0.20356	38.7	2167.20
120	0.4860	0.18205	47.3	2648.80

TABLE 7

200 gms soil + 0.1% N as NaNO_3

Period of exposure in days	Total carbon %	Total nitrogen %	Nitrogen loss % lbs per acre	
0	0.1129	0.13162	---	---
60	0.1053	0.10411	27.5	616.00
120	0.0961	0.09682	34.8	779.52

TABLE 8

200 gms soil + 0.1% N as NaNO_3 + 0.5% C as Sunn-hemp

0	0.5961	0.15166	---	---
60	0.4524	0.13105	20.6	461.44
120	0.4113	0.12554	26.1	584.40

TABLE 9

200 gms soil + 0.1% N as NaNO_3 + 0.5% C as Alfalfa

0	0.6026	0.15469	---	---
60	0.4976	0.13228	22.4	501.76
120	0.4689	0.12638	28.3	633.96

TABLE 10

200 gms soil + 0.25% N as NaNO_3

0	0.1118	0.27817	---	---
60	0.1017	0.21292	26.1	1461.60
120	0.0924	0.19741	32.3	1808.80

TABLE 11

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Sunn-hemp

0	0.5908	0.29474	---	---
60	0.4426	0.28649	18.9	1058.40
120	0.4001	0.23448	23.7	1327.20

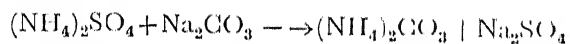
TABLE 12

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Alfalfa

0	0.5972	0.29930	---	---
60	0.4923	0.22855	20.3	1136.80
120	0.4606	0.23480	25.8	1444.70

DISCUSSION

A careful study of the foregoing results clearly indicates that a large portion of nitrogen added to the soil in the form ammonium sulphate is not retained by the alkali soil and is lost to the atmosphere. In alkali soil there is an additional source of loss due to the formation of ammonium carbonate which decomposes giving off ammonia :—



It is interesting to note that the loss of nitrogen in the case sodium nitrate is less pronounced. When 0.1% nitrogen as ammonium sulphate is added, the

percentage loss is 48.4 but when the same dose of sodium nitrate is added the percentage loss is 27.5. In case of ammonium sulphate there is a greater possibility of the formation of ammonium ion which can easily undergo nitrification and hence greater loss has been observed in this case. Some losses of nitrogen may be due to the liberation of ammonia ions derived from ammonium sulphate, and carbonate ions from sodium carbonate present in alkali soil. As sodium nitrate is already in nitrate state the question of nitrification does not arise, but some nitrite and ammonia are formed due to the reduction of nitrates by the soil humus or the organic matter added thus causing the loss.

Martin and associates⁹ have reported that when urea or ammonium salts were added to the alkaline Arizona soil, nitrogen can be lost to the atmosphere in the form of ammonia and this may be of considerable importance in alkali soils under hot, wet conditions. The rate of loss of nitrogen is very rapid in the beginning but it slows down with the lapse of time. It is clear from the table No. 1 that when 0.1 % nitrogen is added as ammonium sulphate the loss is 48.4 % in 60 days while it is only 59.2 % in 160 days. Jewitt¹⁰ also got similar results with the alkali soil.

When carbonaceous matter like sunn-hemp or alfalfa were added along with nitrogenous compounds to the alkali soil, the loss of nitrogen is retarded as is clear from the results. Foregoing results also show that on addition of sunn-hemp the loss of nitrogen in case of ammonium sulphate is decreased from 48.4 % to 40.4 % in 60 days. It seems that sunn-hemp and alfalfa, which are rich in carbonaceous materials, act as negative catalysts and thus check the loss of nitrogenous compounds. It is a well-known phenomenon that carbohydrates preserve body proteins from undergoing oxidation as shown by Hirschler¹¹ and Doryland¹² and it is just likely that carbonaceous matter present in the soil may also act as negative catalyst and protect the soil protein and nitrogenous matter from oxidation. It is interesting to note that sunn-hemp, which oxidizes more easily than alfalfa checks the loss to a greater extent. Dhar and Narayanan¹³ also found that organic substances like sugar, starch, gum, lignin, chlorophyll and alcohol retarded the decomposition of ammonium nitrite solution. Mukerji and Agarwal¹⁴ have shown that the addition of green manure in combination with oil cakes or ammonium sulphate leads to marked increase in the field of wheat as compared with that due to green manure and artificials alone.

It may, therefore, be concluded that the incorporation of organic matter like sunn-hemp and alfalfa with nitrogenous fertilizers is a beneficial process for improving nitrogen status of the alkali soil by retarding the loss of nitrogen.

SUMMARY

When ammonium sulphate or sodium nitrate is added to the alkali soil, an appreciable amount of nitrogen is lost in four months, the loss being more with ammonium sulphate than with sodium nitrate. The addition of organic matter in the form of sunn-hemp or alfalfa checks the nitrogen loss appreciably which is due to the fact that carbonaceous matter present in them acts as a negative catalyst and hence saves nitrogen from further loss.

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EFFECT OF ROCK PHOSPHATE AND BASIC SLAG, REINFORCED WITH LIGNITE AND COAL, ON NITROGEN STATUS, AVAILABILITY OF PHOSPHATE AND pH OF USAR SOIL

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It has been estimated that approximately one-third of the land surface of the earth is arid or semi-arid. There are vast tracts of alkali lands in India, and in Uttar Pradesh alone there are more than 4 million acres of alkali land. Previously Dhar and co-workers¹ have used molasses, press mud and oil-cakes for the reclamation of alkali soil. Recently Dhar² has postulated a new but significant rôle played by phosphates in preservation of soil nitrogen and its enrichment through the fixation of additional amount of nitrogen from atmosphere. Dhar and Pal³ obtained marked increase in soil nitrogen status, availability of phosphate and fall in pH value of alkaline soil when disodium hydrogen phosphate was added with carbonaceous matter like lignite and coal.

The present studies have been made with a view to find out the influence of rock phosphate and basic slag, on the soil nitrogen status, availability of phosphate and pH of the alkaline soil, with lignite and coal as energy materials.

METHOD AND MATERIALS

Total carbon was estimated by the method of Robinson, Mcleans and Williams.⁴ Total nitrogen was estimated by the Kjeldahl method as modified by Treadwell and Hall.⁵ Exchangeable calcium was estimated by Hissink's method.⁶ Available phosphate was estimated by Dyer's method.⁷ pH was determined by Beckman pH meter.

200 grams of well-dried and powdered (passed through 80 mesh sieve) alkali soil was taken in shallow enamelled dishes, to which lignite and Assam coal at the rate 1% carbon along with rock phosphate (Trichinopoly) and basic slag (from Tata Iron & Steel Co., India) at the rate 0.138% P_2O_5 were added. The mixtures were thoroughly mixed. The soil was stirred daily, the moisture content of the dishes was maintained at 20%. The dishes were exposed to electric bulb (500 watt) light, placed at a distance of 1 yard from the dishes. The samples were taken after drying the soil completely.

RESULTS

TABLE 1

200 grms soil + 1% C as Assam coal.

Period of exposure in days	Total carbon %	Total nitrogen %	Exchangeable calcium m. e. %	Available P_2O_5 %	Efficiency mgm	pH
0	1.1136	0.04881	3.8	0.01642	...	10.30
150	1.0234	0.05018	4.3	0.01691	15.1	9.35
300	0.9500	0.05068	4.9	0.01756	17.3	8.40
510	0.8496	0.04046	5.3	0.01780	...	8.10

TABLE 2

200 gms soil + 1% C as Assam coal + 0.138% P_2O_5 as Rock phosphate						
Period of exposure in days	Total carbon %	Total nitrogen %	Exchangeable calcium m. e. %	Available P_2O_5 %	Efficiency mgm	pH
0	1.1136	0.04881	3.8	0.01928	...	10.3
150	0.9801	0.05098	4.8	0.03022	16.3	9.0
300	0.9310	0.05248	5.4	0.04126	20.1	8.1
510	0.8063	0.04608	5.9	0.04678	...	7.8

TABLE 3

200 gms soil + 1% C as Assam coal + 0.138% P_2O_5 as Basic slag						
0	1.1136	0.04881	3.8	0.02981	...	10.30
150	0.9521	0.05256	5.0	0.03316	23.2	9.10
300	0.9054	0.05516	5.7	0.03651	30.4	8.00
510	0.7629	0.04780	6.2	0.03673	...	7.65

TABLE 4

200 gms soil + 1% C as Lignite						
0	1.1136	0.04592	3.80	0.01642	...	10.30
150	1.0012	0.04697	4.20	0.01681	9.3	9.40
300	0.9221	0.04869	4.65	0.01738	14.5	8.70
510	0.7706	0.03940	5.10	0.01756	...	8.25

TABLE 5

200 gms soil + 1% C as Lignite + 0.138% P_2O_5 as Rock phosphate						
0	1.1136	0.04592	3.80	0.01929	...	10.30
150	0.9668	0.04768	4.55	0.01315	11.9	9.15
300	0.8987	0.04963	5.34	0.04263	17.2	8.40
510	0.7183	0.03885	5.80	0.04696	...	8.05

TABLE 6

200 gms soil + 1% C as Lignite + 0.138 % P_2O_5 as Basic slag						
0	1.1136	0.04592	3.80	0.02980	...	10.30
150	0.9443	0.04853	4.75	0.03317	15.4	9.20
300	0.8595	0.05197	5.54	0.03652	23.8	8.10
510	0.7105	0.03917	5.90	0.03681	...	7.75

DISCUSSION

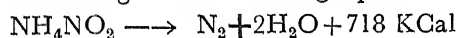
From the foregoing results it is clear that Assam coal and lignite containing organic matter are slowly oxidized in contact with light and air, when added to the alkali soil. From the results it is clear that nitrogen status of the alkali soil increases slowly up to 300 days and after that period loss of nitrogen takes place and C/N ratio of the mixture increases. We have observed that the amount of nitrogen fixed or the efficiency of the system is higher when rock phosphate and basic slag have been added along with coal or lignite. Similar results have been obtained by Dhar.² Raychaudhuri and Subbiah³ have also found that by adding phosphate fertilizers the soil nitrogen status is almost

doubled. Dhar⁹ has explained the increase of nitrogen fixation on the addition of phosphate in the following words :—

“It seems that phosphate plays a vital role in the improvement and maintenance of nitrogen status of the soil. The proteins that are present in the soil humus are likely to be stabilized by the formation of nucleoproteins, etc. with the combination of protein and phosphate or other substances. The organic matter present in soil or added to it undergoes slow oxidation in the soil aided by the light and presence of alkali, and fixes nitrogen of the air and form protein in this process. Under ordinary condition, the proteins formed undergo ammonification and nitrification which are accelerated by light absorption and forms nitrates in the following way :—



In this series of reactions the unstable substance, ammonium nitrite, is formed and decomposed according to the following equation :—

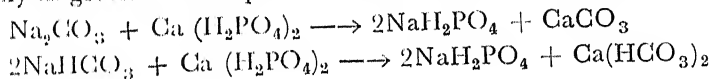


Hence along with nitrogen fixation and formation of proteins due the oxidation of energy materials, ammonification and nitrification, which oppose the increase of the protein in the soil, takes place and thus the amount of protein remaining in the soil tends to decrease. Hence the apparent efficiency of nitrogen fixation appears to fall off when ammonification and nitrification take place. But in the presence of large amounts of phosphates in the system more or less stable phospho-proteins are formed by the combination of proteins and phosphorus compounds. These compounds seem to resist nitrification and ammonification and loss of nitrogen is better than protein alone. This seems to be an important reason why the efficiency of nitrogen fixation of soils, both under sterile and unsterile conditions appear larger in presence of increasing amounts of phosphates.”

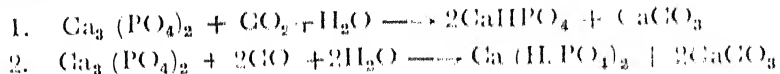
From our results it is also clear that there is an appreciable increase in exchangeable Ca and fall in pH value. This is due to the fact that during the process of slow oxidation of coal and lignite CO_2 is liberated, which in presence of water forms carbonic acid. This weak acid reacts with calcium carbonate forming calcium bicarbonate, Ca ions thus brought into solution replace Na ions as given in the equation below :—

1. $\text{H}_2\text{CO}_3 + \text{CaCO}_3 \longrightarrow \text{Ca}(\text{HCO}_3)_2$
2. $\text{Ca}(\text{HCO}_3)_2 + \text{Na clay} \longrightarrow \text{Ca clay} + 2\text{NaHCO}_3$

In other words the amount of Ca brought into available form and the amount of Na ions replaced depends on the amount CO_2 produced in the system. Kelley¹⁰ got similar results by growing Bermuda grass. It is interesting to note that in the presence of rock phosphate and basic slag the amount of exchangeable calcium is sufficiently increased and fall in pH value is also greater, which is due to the greater amount of CO_2 produced in the system and secondly due to the formation of dicalcium and monocalcium phosphates in the system. Monocalcium phosphate can readily convert the sodium carbonate and sodium bicarbonate present in alkali soil into sodium phosphate, calcium carbonate and calcium bicarbonate respectively as given in the equation thus reclaiming the alkali soil.



It is also seen from the results that the availability of phosphates is greater with rock phosphate and basic slag. This is due to the greater amount of CO_2 liberated which reacts with tricalcium phosphate, present in rock phosphate and basic slag, and thus forms the dicalcium and monocalcium phosphates respectively.



The dicalcium and monocalcium phosphates are more soluble than tricalcium phosphate and thus the availability is increased. Magistad and Christiansen¹¹ have obtained similar results. Mattson and co-workers¹² reported that lower the pH value, greater is the amount of available phosphate. Pal¹³ also obtained similar results.

Thus the results recorded clearly indicate that systematic use of rock phosphate and basic slag with appropriate organic matter is helpful in increasing and improving the quality of alkali soil.

SUMMARY

The alkali soils are poor in nitrogen, carbon and phosphates. Application of phosphates, e.g., rock phosphate and basic slag resulted in the improvement of these soils. The soil nitrogen status is increased. Exchangeable calcium and available P_2O_5 increase appreciably. Fall in pH is sufficiently great. Thus inclusion of any organic matter with phosphates offer a rapid method of improving the fertility of alkali soils which are poor in nitrogen and carbon.

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STUDIES ON THE RELATIVE EFFECTS OF TRICHINOPOLY ROCK
PHOSPHATE AND BASIC SLAG, WHEN REINFORCED WITH
ORGANIC MATTER LIKE SUNN-HEMP AND ALFALFA,
IN RETARDING THE NITROGEN LOSS WHEN
NITROGENOUS FERTILIZERS LIKE AMMO-
NIUM SULPHATE AND SODIUM NITRATE
ARE ADDED TO ALKALI SOIL

By

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Phosphorus has sometimes been called the master-key to agriculture. Its importance in general farming is indicated by the fact that low crop production is due more often to a lack of phosphorus than to the lack of any other element. Unlike nitrogen, very little information is available on the manuring with phosphates under Indian conditions. There are places in India where soils are poor in phosphates and the application of phosphates under Indian conditions is now gaining in importance.

Phosphates are available in many forms *e.g.*, bones, rock phosphates, basic slag and other foreign products. In summarising the work on phosphates in India it is clear that apart from few experiments with ammophos, most of the work was done with superphosphate and bone-products. Das¹ has indicated that manurial value of phosphates is enhanced when they are applied with bulky organic manures. DeClouse² was of the opinion that in acidic soil the effect of superphosphate and Renohy perphosphate was equal but in alkaline soil superphosphate gives better response. A Committee Report of Board of Agriculture for Scotland³ stated that the effect of phosphatic fertilizers was not exhausted in the first year and that lasted for three seasons.

It is seen that very little information is available about the relative effect of different phosphates in retarding the nitrogen loss when they are reinforced with organic matter. In this paper we have studied this problem systematically and have drawn definite conclusions.

METHOD AND MATERIALS

Total carbon was estimated by the method of Robinson, Mcleans and Williams.⁴ Total nitrogen was estimated by the Kjeldahl method as modified by Treadwell and Hall⁵ using salicylic acid for the reduction of nitrites and nitrates.

200 grams of well powdered alkali soil (from Soraon, Allahabad) after having been passed through 80 mesh sieve were taken in enamelled dishes. 0.1% and 0.25% nitrogen was added either in the form ammonium sulphate or sodium

nitrate respectively. 0.5% carbon was added either in the form of sunn-hemp or alfalfa. In one set 0.25% P_2O_5 as Trichinopoly rock phosphate was added and in another set of experiment 0.25% P_2O_5 in the form of basic slag was added. 20% moisture in the form of distilled water was added in each dish. These dishes were then exposed to the artificial light from a 500 watt electric bulb. The contents of the dishes were stirred on alternate days to help aeration. Moisture content was maintained at 20%. After an interval of 60 days and 120 days samples were taken out from each dish, oven-dried and analysed for the total carbon and nitrogen.

RESULTS

Experiments with Trichinopoly rock phosphate

Average temp.—30°C.

TABLE 1

200 gms soil + 0.1% N as $(NH_4)_2 SO_4$ + 0.5% C as Sunn-hemp + 0.25% P_2O_5

Period of exposure in days	Total carbon %	Total nitrogen %	Nitrogen Loss %	Lbs per acre
0	0.5918	0.15055	---	---
60	0.4480	0.11804	32.5	728.00
120	0.4131	0.11376	36.7	824.32

TABLE 2

200 gms soil + 0.1% N as $(NH_4)_2 SO_4$ + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5982	0.15354	---	---
60	0.4870	0.11923	34.3	768.32
120	0.4548	0.11443	39.3	875.85

TABLE 3

200 gms soil + 0.25% N as $(NH_4)_2 SO_4$ + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5887	0.29324	---	---
60	0.4586	0.21723	30.4	1702.40
120	0.4168	0.20399	35.7	1999.20

TABLE 4

200 gms soil + 0.25% N as $(NH_4)_2 SO_4$ + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5940	0.29773	---	---
60	0.4972	0.21748	32.1	1797.60
120	0.4788	0.19347	37.3	2088.80

TABLE 5

200 gms soil + 0.1% N as $NaNO_3$ + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5911	0.15132	---	---
60	0.4335	0.13692	14.1	322.56
120	0.4014	0.18113	20.0	452.48

TABLE 6

200 gms soil + 0.1% N as NaNO_3 + 0.5% C as Alfalfa + 0.25% P_2O_5

Period of exposure in days	Total carbon %	Total nitrogen %	Nitrogen %	Loss lbs per acre
0	0.5974	0.15335	...	...
60	0.4803	0.13725	16.1	360.60
120	0.4467	0.13214	21.2	474.88

TABLE 7

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5858	0.29224	...	...
60	0.4249	0.25923	13.2	739.20
120	0.3912	0.24549	18.7	1047.20

TABLE 8

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5922	0.29673	...	...
60	0.4765	0.25972	14.8	828.80
120	0.4372	0.24774	19.6	1097.60

Experiments with Basic slag

TABLE 9

200 gms soil + 0.1% N as $(\text{NH}_4)_2\text{SO}_4$ + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5842	0.14741	...	...
60	0.4318	0.11762	29.8	667.52
120	0.4045	0.11330	34.1	763.84

TABLE 10

200 gms soil + 0.1% N as $(\text{NH}_4)_2\text{SO}_4$ + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5856	0.15030	...	...
60	0.4709	0.11860	31.7	710.08
120	0.4468	0.11400	36.3	813.12

TABLE 11

200 gms soil + 0.25% N as $(\text{NH}_4)_2\text{SO}_4$ + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5761	0.28716	...	...
60	0.4356	0.21814	27.6	1545.60
120	0.3930	0.20616	32.8	1836.80

TABLE 12

200 gms soil + 0.25% N as $(\text{NH}_4)_2\text{SO}_4$ + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5816	0.29149	...	...
60	0.4775	0.21848	29.2	1635.20
120	0.4578	0.20347	35.6	1993.60

TABLE 13

200 gms soil + 0.1% N as NaNO_3 + 0.5% C as Sunn-hemp + 0.25% P_2O_5

Period of exposure in days.	Total carbon %	Total nitrogen %	Nitrogen Loss lbs per acre.	
0	0.5788	0.14723	---	---
60	0.4223	0.13363	12.6	282.24
120	0.3953	0.12973	17.5	392.00

TABLE 14

200 gms soil + 0.1% N as NaNO_3 + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5848	0.15011	---	---
60	0.4653	0.13562	14.5	324.80
120	0.4407	0.13042	19.7	441.28

TABLE 15

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Sunn-hemp + 0.25% P_2O_5

0	0.5731	0.28623	---	---
60	0.4136	0.25798	11.3	632.80
120	0.3846	0.24654	18.7	1047.20

TABLE 16

200 gms soil + 0.25% N as NaNO_3 + 0.5% C as Alfalfa + 0.25% P_2O_5

0	0.5788	0.29148	---	---
60	0.4597	0.25798	13.4	750.40
120	0.4352	0.24547	18.2	1019.20

DISCUSSION

The foregoing results clearly show the importance of phosphates in retarding the loss of nitrogen. It is clear from the results that when rock phosphate or basic slag are added with sunn-hemp or alfalfa along with nitrogenous fertilizers, they retard the loss to a greater extent. This is due to the fact that phosphates may retard the loss in three ways. Firstly they may form stabler phosphoproteins and thus the denitrification will be lessened, secondly by an increase in nitrogen fixation as shown previously by Dhar⁶ and since observed loss is the balance of total nitrogen loss occurring and nitrogen fixation going on side by side it goes a long way in neutralizing the loss. Thirdly Ca ions introduced in the system by the addition of rock phosphate or basic slag may react with ammonium nitrite to give calcium nitrite, which is more stable than ammonium nitrite. Ghosh⁷ showed that the addition of potassium chloride appreciably checks the loss of nitrogen due to the formation of more stable potassium nitrite. These results are in agreement with some of the results obtained at Rothamsted⁸ on the crop yield per acre on a soil treated with ammonium sulphate containing enough phosphate and potassium salts. From our results it is also clear that basic slag is a better retarder of nitrogen loss from the alkali soil than rock phosphate, when they are reinforced with organic matter.

It may, therefore, be concluded that incorporation of phosphates in the form of basic slag or rock phosphate with organic matter like sunn-hemp and

alfalfa is a beneficial process for improving the nitrogen status of the alkali soil by retarding the nitrogen loss from the artificial nitrogenous fertilizers which are used to make the alkali soil fertile.

SUMMARY

When rock phosphates or basic slag are added with organic matter like sunn-hemp or alfalfa, they retard the nitrogen loss from the alkali soil, in which nitrogenous fertilizers were added either in the form of ammonium sulphate or sodium nitrates to a greater extent. The efficiency of basic slag is greater in retarding the loss of nitrogen in comparison to rock phosphate.

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REPEATED ADSORPTION OF SODIUM CARBONATE FROM SOLUTIONS BY A NORMAL SOIL AND ITS SUBSEQUENT LEACHINGS WITH WATER

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Mondesir (1888) established the principle by which Na_2CO_3 and NaHCO_3 are produced in the soil and he was able to prepare 100 gms of trona ($\text{Na}_2\text{CO}_3 \cdot \text{NaHCO}_3 \cdot 2\text{H}_2\text{O}$) from 1 kgm of calcareous soil by 20 repetitions of NaCl water and carbonated water washings. Later Gedroiz, (1912), Dominicus, (1918), Prescott, (1922), Cummins and Kelley, (1923) and Burgess (1928) showed that by the application of the principle established by Mondesir, Na_2CO_3 may be formed in alkali soils.

The association of black alkali soil formation with Na_2CO_3 and NaHCO_3 of irrigation waters, as originally pointed out by Hilgard and Loughridge was utilized by Stabler as early as 1911 in his rating formulae for irrigation waters. Stabler (1911) stated that Na_2CO_3 is twice as undesirable as NaCl and 10 times as undesirable as Na_2SO_4 whilst Scofield asserted that the harmfulness caused by $\text{CO}_3^{=}$ and HCO_3' has been over-rated.

Eaton (1950) pointed out that irrigation water containing HCO_3' in excess of its equivalent $\text{Ca}^{++} + \text{Mg}^{++}$ will leave a residue of NaHCO_3 upon evaporation and the pH of the soil will increase up to 8.0. It has also been found out by him that the hazard of using a water increased rapidly as the sodium percentage increased above 60 and decreased as the percentage fell below that level. Recently (1947), it has been recommended that if a soil has a good structure and is permeable, even 75% sodium in irrigation waters does not give trouble provided that total salt content is low.

Puri and Uppal, (1942) have given the mechanism of the action of Na_2CO_3 on a calcium soil and shown that Na_2CO_3 reacts quantitatively with calcium soil precipitating the whole of exchangeable calcium as CaCO_3 and resulting in the formation of Na-soil. The non-availability of calcium in alkali soils has been assigned by them to a high pH value and not to a high Na/Ca ratio. Puri, (1949) has used 0.1% Na_2CO_3 solution to reduce the seepage losses from canal beds by 50%. Na_2CO_3 has also been used in mechanical analysis of soils as a dispersing agent.

The present studies were carried out in the laboratories of the Sheila Dhar Institute of Soil Science with a view to find out the effect of repeated application of sodium carbonate solution to a normal soil on the adsorption of carbonate ions and the release of adsorbed sodium and carbonate ions from the soil by successive leachings with distilled water. The changes in the pH values of the filtrates after each additions of sodium carbonate solution or of subsequent water leachates have also been observed.

EXPERIMENTAL

20 gms. of the normal soil having a pH 7.6 and of known chemical composition were shaken with 100c. c. solutions of Na_2CO_3 (A. R.) of N/50, N/100, N/200 and N/500 concentrations in glass stoppered bottles for 2 hours and filtered through Buchner funnels under pressure after 24 hours' contact. The filtrates were collected and kept aside for CO_3'' , HCO_3' and pH determinations. 100 c.c. of Na_2CO_3 solutions were again added upon the respective Buchner funnels containing the soil and the filtrates were again collected and kept aside for determinations. In this way sodium carbonate solutions were added to the respective Buchner funnels till the filtrates failed to show any deficit of carbonate ions from the solutions. Now the soils left on the funnels after adsorption of Na_2CO_3 were repeatedly washed with 50 c.c. lots of distilled water till the leachates failed to give any appearance of carbonates.

The determinations of CO_3'' and HCO_3' in the filtrates or water leachates were made by titrating a known volume with dilute HCl solution using phenolphthalein and methyl orange indicators to find out the first and second end points as described by Piper (1947). pH of extracts was determined by Beckman pH-meter and chemical constituents in the HCl extract of normal soil by methods prescribed by Wright, (1934) and A.O.A.C., (1945). The term "adsorption" of carbonate all along implies the disappearance of carbonate ions from the solution. The percentage of adsorption has been calculated on the basis of 100 gms. of soil.

RESULTS AND DISCUSSIONS

TABLE 1 (a)

20 gms soil + 100 c.c. of N/50 Na_2CO_3 pH 11.0					
No. of extracts	pH of the extracts	Analysis of the extract		Adsorption of carbonate as Na_2CO_3	
		CO_3'' left as Na_2CO_3 (in gms)	HCO_3' produced as NaHCO_3 (gms)	% adsorbed of the total	% adsorption
1	9.4	0.01892	0.04956	82.1	0.4355
2	9.8	0.05300	0.03890	50.0	0.2650
3	10.1	0.07760	0.03150	26.8	0.1420
4	10.5	0.09200	0.03740	14.3	0.0700
5	10.9	0.10400	0.03640	1.9	0.0100
Total	...	...	0.19376	...	0.9225

TABLE 1 (b)

Above treated soil + 50 c.c. distilled water each time			
No. of washings	pH of leachate	Analysis of the leachate per 100 gms of soil	
		CO_3'' present as Na_2CO_3	HCO_3' present as NaHCO_3
1	9.65	0.06600	0.07495
2	9.00	0.05670	0.07140
3	8.40	0.00446	0.13480
4	8.30	0.00223	0.08980
5	8.00	...	...
Total	...	0.12939	0.30095

TABLE 2 (a)

20 gms + 100 c.c. of N/100 Na_2CO_3 pH 10.5					
Analysis of the extract			Adsorption of carbonate as Na_2CO_3		
No. of extracts	pH of the extract	$\text{CO}_3^{''}$ left as Na_2CO_3 (in gms)	HCO_3' produced as NaHCO_3 (gms)	% adsorbed of the total	% adsorption
1	8.9	0.00283	0.03133	94.6	0.2508
2	9.2	0.01700	0.03200	67.9	0.1800
3	9.8	0.02120	0.03440	60.0	0.1590
4	10.1	0.03030	0.02688	42.8	0.1135
5	10.4	0.05300	0.02488	0.00	0.0000
Total		...	0.14949	...	0.7033

TABLE 2 (b)

Above treated soil + 50 c.c. distilled water each time			
Analysis of the leachate per 100 gms of soil			
No. of washings	pH of leachate	$\text{CO}_3^{''}$ present as Na_2CO_3	HCO_3' present as NaHCO_3
1	9.4	0.03337	0.04200
2	9.6	0.03337	0.05960
3	9.3	0.02385	0.03360
4	9.3	0.02385	0.02550
5	8.5	0.00450	0.04200
6	7.7	...	0.02550
7	...	...	0.02650
8	...	...	0.02100
Total		0.11894	0.02757

TABLE 3 (a)

20 gms soil + 100 c.c. of N/200 Na_2CO_3 pH 10.2					
Analysis of the extract			Adsorption of carbonate as Na_2CO_3		
No. of extracts	pH of the extracts	$\text{CO}_3^{''}$ left as Na_2CO_3 (in gms)	HCO_3' produced as NaHCO_3 in gms)	% adsorbed of the total	% adsorption
1	8.0	0.00000	0.0398	100.0	0.13250
2	8.5	0.00228	0.0269	91.3	0.12110
3	8.9	0.00456	0.0238	82.7	0.10970
4	9.5	0.01145	0.0210	56.0	0.07430
5	10.0	0.02000	0.0201	24.5	0.03250
6	10.1	0.02660	0.0100	...	...
Total		...	0.1416	...	0.47010

TABLE 3 (b)

Above treated soil + 50c. c. distilled water each time

No. of washings	pH of leachate	Analysis of the leachate per 100 gms of soil	
		CO ₃ ' present as Na ₂ CO ₃	HCO ₃ ' present as NaHCO ₃
1	9.3	0.02284	0.01805
2	9.1	0.01150	0.01090
3	8.9	0.00914	0.01090
4	9.2	0.01829	0.00725
5	8.9	0.00914	0.01800
6	8.5	0.00450	0.01090
7	7.5	...	0.01100
Total		0.07541	0.08700

TABLE 4 (b)

pH10.0

20 gms soil + 100 c.c. N/500 N₂CO₃

No. of extracts	pH of the extracts	Analysis of the extracts		Adsorption of carbonate as Na ₂ CO ₃	
		CO ₃ ' left as Na ₂ CO ₃ (in gms)	HCO ₃ ' produced as NaHCO ₃ (gms)	% adsorbed of the total	% adsorption
1	7.7	...	0.02965	100.0	0.053
2	7.7	...	0.01490	100.0	0.053
3	7.8	...	0.01490	100.0	0.053
4	8.0	...	0.01680	100.0	0.053
5	8.2	...	0.01490	100.0	0.053
6	8.2	...	0.01490	100.0	0.053
7	8.2	...	0.01600	100.0	0.053
8	8.7	0.00182	0.01680	82.8	0.043
9	9.0	0.00273	0.01000	74.2	0.039
10	9.0	0.00273	0.01000	74.2	0.039
11	9.9	0.01000	0.01100	5.6	0.003
12	10.1	0.01060	0.01100	...	...
Total		...	0.18085	...	0.495

TABLE 4 (b)

Above treated soil + 50 c.c. distilled water each time

No. of washings	pH of leachate	Analysis of the leachate per 100 gms of soil	
		CO ₃ ' present as Na ₂ CO ₃	HCO ₃ ' present as NaHCO ₃
1	8.0	...	0.03610
2	7.5	...	0.01800
3	7.5	...	0.01800
4	7.5	...	0.01800
5	7.5	...	0.01800
Total			0.10810

TABLE 5

Chemical analysis (·) of normal soil (oven-dried)

Loss on ignition ...	3·88	CaO ...	0·9920
HCl insolubles ...	81·64	MgO ...	1·1580
Sesquioxides ...	11·17	K ₂ O ...	0·0735
Fe ₂ O ₃ ...	4·12	P ₂ O ₅ ...	0·0790

TABLE 6

Amounts of CO₃^{''} and HCO₃['] in the adsorption and water leaching systems

Amount of	Concentrations of Na ₂ CO ₃ added to soil			
	N/50	N/100	N/200	N/500
1. CO ₃ ^{''} adsorbed as Na ₂ CO ₃ — %	0·9225	0·7033	0·4701	0·4950
2. HCO ₃ ['] (as NaHCO ₃) in — % the Na ₂ CO ₃ -filtrates	0·9688	0·7474	0·7080	0·9040
3. HCO ₃ ['] (as NaHCO ₃) in — % the water extracts	0·3009	0·2757	0·0870	0·1081
4. CO ₃ ^{''} given out as Na ₂ CO ₃ — % in water extracts	0·1294	0·1189	0·0754	...
5. Na ₂ CO ₃ left adsorbed in — % (—)0·0004 (—)0·0557 (—)0·019 (—)0·1350 the soil 1—(2+3+4) (after converting NaHCO ₃ to equivalent Na ₂ CO ₃).				

From the above tables it is clear that at lower concentrations of sodium carbonate solution, the whole of carbonate ions are absorbed by the soil when the solution is added for the first time but gradually the adsorption goes on decreasing till no adsorption of carbonate ions takes place. The percent-adsorption (amount of Na₂CO₃ adsorbed by 100 gms of soil) is highest with greatest concentration and it decreases as the concentration decreases. However, the adsorption of CO₃^{''} ions is not directly proportional to the concentrations of the solutions used.

The pH of the extracts obtained after each addition of Na₂CO₃ to the soil is always less than the pH of the original solution added which shows that the removal of CO₃^{''} ions has taken place. The pH of the extracts gradually increases till it equals the original pH values of the solutions used. But, the pH of the water extracts follows a reverse order as is clear from the tables 1 (b), 2 (b), 3 (b), and 4 (b). The pH of water extracts is always on the alkaline side, as high as 9·6 at highest concentration of Na₂CO₃ treatment and subsequent water leaching and as low as 8·0 with a lowest concentration of N/500 Na₂CO₃ after a similar leaching with water. The pH of the extracts gradually falls off as leaching with water is continued, most rapidly where the Na₂CO₃ concentration added as a pretreatment to the soil is least.

Na₂CO₃ given out in the water extracts is never greater than 1/5 - 1/6 of the total Na₂CO₃ adsorbed by the soil. With N/500 concentration, there is practically no liberation of Na₂CO₃.

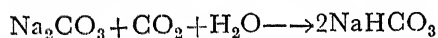
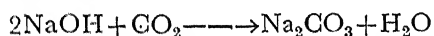
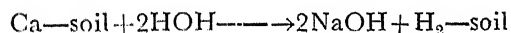
There is always a simultaneous production of NaHCO₃ when sodium carbonate solution is added to the soil and filtered. The amount produced is

approximately equal to the amounts of sodium carbonate adsorbed by the soil as is evident from table No. 6. Bicarbonates are produced even when carbonates cease to appear in the water extracts and the amount produced is always greater than carbonates. The most interesting feature of the experiments is that at N/500 concentration of sodium carbonate, though cent per cent adsorption of carbonate takes place, in the water extract no carbonate appears.

The adsorption of sodium carbonate by the normal soil takes place according to the following equation :—



The insoluble calcium carbonate formed by the interaction of sodium carbonate and calcium of the soil, is unable to supply any carbonate ions at such high pH values of 10–11 of sodium carbonate used in these experiments, hence, the carbonate ions appearing into the soil extracts after leaching it with distilled water come from the hydrolysis of the sodium soil formed by the action of sodium carbonate solution, according to the following equations :—



Thus the carbonates and bicarbonates of sodium are produced as the experiments are open to atmospheric carbondioxide. As the filtration process is also a very slow one, some carbonate is converted into bicarbonate.

From table No. 6, one very interesting point is observed. The amount of bicarbonate and sodium carbonate present in the extracts and water leachates when subtracted from the amount of sodium carbonate adsorbed by the soil, the values are always negative. It shows that the amount of sodium carbonate given out by a soil is greater than what has been adsorbed whilst the results in tables Nos. 4 (a) and 4 (b) clearly show that the sodium carbonate adsorbed is not hydrolysed and liberated by leaching with water. Hence these experiments indicate that the amounts of bicarbonate found in the extracts or leachates do not give any indication as to the adsorption of sodium carbonate from the solutions. It is also clear that the soil is able to furnish bicarbonate ions from some other source except adsorbed sodium carbonate. The alkaline earth carbonates easily hydrolyse and dissolve in presence of carbon dioxide to give out their bicarbonates. As in these experiment from the amount of CO_3'' and HCO_3' , the amount of sodium carbonate and bicarbonate has been calculated, the two values do not coincide and hence negative values are obtained.

The preferential adsorption of CO_3'' ions from sodium carbonate is due to the formation of insoluble calcium and magnesium carbonates as well as ferric and aluminium carbonate.

All these results show that the sodium carbonate present in the black alkali soils suffers a series of adsorption phenomenon and gives rise to high pH values. At the same time the amount of sodium carbonate in the adsorbed state in the soil may be high and yet the soil may fail to give carbonate ions when shaken with water.

SUMMARY

A normal soil can go on adsorbing sodium carbonate from the washings of neighbouring black alkali soil and may finally convert into a soil whose water extracts furnish both the soluble carbonate and bicarbonate ions.

A low concentration of sodium carbonate in solutions results in a relatively greater adsorption of sodium carbonate and a consequent lesser release of sodium carbonate in the water extracts than a higher concentration.

The amounts of $\text{CO}_3^{''}$ and HCO_3' in the water extracts when computed in terms of sodium carbonate do not give a clear picture of sodium carbonate adsorption by the soil.

The carbonates and bicarbonates in the water extracts originate from the hydrolysis of sodium ions of the exchange complex of the soil.

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INFLUENCE OF RAW BONE MEAL AND DIFFERENT ALGERIAN
ROCK PHOSPHATES INCORPORATED WITH WHEAT STRAW
ON OXIDATION OF CARBON, pH, EXCHANGEABLE
CALCIUM AND AVAILABLE PHOSPHATE OF
ALKALI SOIL

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Reclamation of alkali soils has attracted the attention of soil workers all over the world. It is claimed that almost all soils can be cultivated if adequate amounts of organic manure can be supplied to such soils.

The principles underlying the reclamation of alkali soils are: firstly to replace some of the adsorbed Na^+ ion by Ca^{++} ion and to remove the released Na^+ ions from the surface soil. Secondly permeability of the soil should be improved and stabilized to facilitate leaching thereby ameliorating most of the defects of alkali soil.

Almost all unused alkali soils are impermeable in nature and improvement of their permeability is the primary problem.¹ These soils can easily be reclaimed by the method advocated by Dhar and Pal.² They recommended the application of any calcium rich amendment along with any organic matter followed by flooding with water having low salt content which produces satisfactory results thereby ameliorating practically all the defects of alkaline soil.

The beginning of the alkalinity has to be ascribed to the washing away of valuable adsorbed Ca^{++} ion and its replacement by Na^+ ion. In other words the beginning of alkali soil is the conversion of Ca soil into sodium one. This is possible by rain water containing traces of sodium salts and irrigation water containing little sodium salts and by sea water. Rain water usually adds 35 lbs of NaCl per acre annually³⁻⁶.

It is well-known that soil humus acts as a marked adsorbent of ions positive and negative *i.e.*, they can affect the acidity and alkalinity of soil markedly and can act as buffer. It is clear therefore that under ordinary condition soil rich in humus cannot be either too acid or too alkaline. Hence there seems to be a fundamental difference between the effect of loss of humus in cold and hot countries. If the humus of the soil is lost in cold countries there is always the possibility of the formation of acid soils and in hot countries in most cases the oxidation of humus is more quick due to high temperature and this is greatly facilitated by the development of alkali. So once the soil in a warm country becomes alkaline and if organic matter is not added the alkalinity may go on increasing chiefly due to the loss of humus.

Thus the remedy is the addition of Ca^{++} ion in the system with the concomitant increase of humus status of alkali soil by the addition of any organic matter to it. This is the permanent cure of alkali soil.

EXPERIMENTAL

The alkali soil used for the purpose of experiments was collected from Soraon, a place approximately 13 miles from Allahabad. It was dried and sieved through 100 mesh. Wheat straw used in the experiment was cut to 30 mesh by an electrical machine.

200 gms of this soil was taken in enamelled dishes. To this soil 5 gms, 10 gms and 20 gms of wheat straw was added. Five different Algerian rock phosphates obtained from France named A, B, C, D₁, and D₂ and raw bone meal was added in combination with wheat straw in these reclamation experiments. They were used in 0.5% and 1.0% doses.

These experiments were continued for twelve months and the contents of dishes were stirred and watered once or twice a week with distilled water.

The estimation of exchangeable calcium was done by Hissink's method.⁷ pH was determined in a suspension of soil and water in the ratio of 1 : 2.5 after being shaken for one hour in a bottle by a Beckman pH meter. The estimation of carbon was done by Robinson, Melcanis and Williams method.⁸ Available phosphate was determined in 2% citric acid extract⁹ of the soil by Lorenz method.¹⁰

RESULTS

TABLE 1

Percentage chemical composition of soil used

Moisture	1.3900
Loss on ignition	2.5000
HCl insoluble	84.5100
Sesquioxide	7.0500
Fe ₂ O ₃	3.3800
CaO	1.0600
MgO	1.3100
K ₂ O	1.1000
P ₂ O ₅	0.1420
Available phosphate (2% citric acid)	0.0318
Exchangeable calcium	3.5720 m.e.
Total carbon	0.1350
Total nitrogen	0.0353
pH	10.0

Analysis of water extract of the soil

	%
Total soluble salts	0.3960
Carbonate	0.1747
Bicarbonate	0.1376
Chloride	0.0302
Sulphate	0.0060

TABLE 2

Analysis of Wheat straw

Carbon	%
Nitrogen	38.23
CaO	0.73
MgO	0.28
P ₂ O ₅	0.06
	0.05

TABLE 3

Analysis of different Rock phosphates and Bone meal

Name of the phosphate	Total P ₂ O ₅ %	Available P ₂ O ₅ %
Algerian rock phosphate A	29.62	7.57
" " " B	26.45	5.62
" " " C	33.37	6.64
" " " D ₁	39.58	3.01
" " " D ₂	39.78	3.09
Raw bone meal	20.17	7.00

DISCUSSION

A close study of foregoing results clearly show that carbonaceous material like wheat straw is oxidized more quickly when added to alkali soil in conjunction with different phosphates than in absence of these materials.

Three doses *viz.* 5 gms, 10 gms and 20 gms of wheat straw as organic matter were used in these experiments in order to see the effect of increasing doses of carbon mixed with different phosphatic amendments. So far as the economy of organic matter is concerned, 5 gm dose produce approximately the same effect as 20 gms in reclaiming alkali soil. It is very interesting to note that the oxidation of organic matter is greater with bone meal in every case than with other phosphates. It is well-known that alkalinity enhances the oxidation, hence more carbon is oxidized in case of bone meal than with different rock phosphates.

It has been observed that the rate of increase of available phosphate varies directly with the rate of oxidation of carbon of organic matter in the system when insoluble phosphates have been added with wheat straw in alkali soil. The increase in the availability of phosphate was obtained in every case even in control experiments where soil alone was incorporated with wheat straw. This is due to the reason that tricalcium phosphate which is present in bone meal and rock phosphate is converted into more soluble form of phosphate such as dicalcium phosphate and monocalcium phosphate by the action of carbonic acid produced during the decomposition, ammonification and nitrification of added organic matter, which is clear from the following equations :—

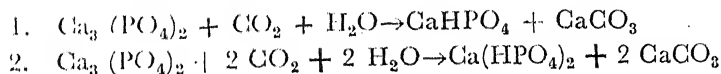


TABLE 4

Reclamation experiments

pH of the soil = 10.0

Ex Ca of the soil = 3.5720 m.e. %

200 grs of soil + 5 grs of Wheat straw

Amendments	Amendment added in grms	% carbon	3 months			6 months			9 months			12 months		
			pH	Ex Ca m.e. %	Ca %	pH	Ex Ca m.e. %	Ca %	pH	Ex Ca m.e. %	Ca %	pH	Ex Ca m.e. %	Ca %
Control	...	1.2400	9.80	4.20	9.50	9.50	5.01	9.01	9.20	5.50	9.00	9.00	5.78	8.78
Algerian rock phosphate	A	1.2400	9.55	5.70	8.90	8.90	7.03	8.30	8.30	7.76	9.80	9.80	8.20	8.20
"	B	1.2400	9.70	5.62	9.00	9.00	6.85	8.50	8.50	7.51	7.90	7.90	8.15	8.15
"	C	1.2400	9.72	5.62	8.90	8.90	7.03	8.40	8.40	7.42	7.85	7.85	8.15	8.15
"	D ₁	1.2400	9.75	5.58	9.05	9.05	6.85	8.55	8.55	7.42	8.00	8.00	8.01	8.01
"	D ₂	1.2400	9.75	5.57	9.20	9.20	6.72	8.60	8.60	7.25	8.05	8.05	8.08	8.08
Raw bone meal		1.2400	9.60	5.80	8.80	8.80	7.10	8.20	8.20	7.61	7.70	7.70	8.30	8.30
Algerian rock phosphate	A	1.2400	9.73	6.25	8.90	8.90	7.45	8.20	8.20	8.10	7.90	7.90	8.53	8.53
"	B	1.2400	9.70	6.12	9.00	9.00	7.32	8.40	8.40	7.85	7.90	7.90	8.49	8.49
"	C	1.2400	9.65	6.20	8.90	8.90	7.45	8.30	8.30	7.83	7.80	7.80	8.53	8.53
"	D ₁	1.2400	9.70	6.17	9.00	9.00	7.32	8.45	8.45	7.85	8.00	8.00	8.37	8.37
"	D ₂	1.2400	9.72	6.15	9.10	9.10	7.20	8.55	8.55	7.72	8.05	8.05	8.37	8.37
Raw bone meal		1.2400	9.49	6.15	8.30	8.30	7.58	8.10	8.10	8.23	7.95	7.95	8.70	8.70

TABLE 5

Reclamation experiments

pH of the soil = 10.0

Ex Ca = 3.5720 m.e. %

200 gms of soil + 10 gms of Wheat straw

Amendment	Amendment added in gms	% carbon	3 months		6 months		9 months		12 months	
			pH	Ex Ca m.e. %	pH	Ex Ca m.e. %	pH	Ex Ca m.e. %	pH	Ex Ca m.e. %
Control	...	2.4700	9.80	4.30	9.40	5.17	7.00	5.80	8.90	6.00
Algerian rock phosphate	A	2.4700	9.55	6.70	8.70	7.30	8.25	7.52	7.80	8.10
"	B	2.4700	9.60	6.50	8.90	7.13	8.40	7.52	7.90	8.05
"	C	2.4700	9.60	6.60	8.80	7.13	8.30	7.52	7.85	8.65
"	D ₁	2.4700	9.65	6.50	8.90	7.20	8.50	7.35	7.95	7.90
"	D ₂	2.4700	9.75	6.54	9.00	7.05	8.50	7.35	8.00	7.90
Raw bone meal	1	2.4700	9.50	6.70	8.60	7.41	8.10	7.80	7.60	8.30
Algerian rock phosphate	A	2.4700	9.10	6.85	8.60	7.91	8.05	8.71	7.70	8.90
"	B	2.4700	9.35	6.70	8.80	7.60	8.30	8.40	7.90	8.85
"	C	2.4700	9.20	6.85	8.70	7.62	8.20	8.53	7.85	8.85
"	D ₁	2.4700	9.45	6.50	8.85	7.50	8.40	8.32	7.90	8.70
"	D ₂	2.4700	9.55	6.40	8.90	7.50	8.50	8.15	7.95	8.70
Raw bone meal	2	2.4700	9.00	7.00	8.50	7.91	7.90	8.71	7.60	9.05

TABLE 6

Reclamation experiment

pH of the soil = 10.0

Ex Ca = 3.5720

200 gms of soil + 20 gms of Wheat straw

Amendments	Amendment added in gms	% carbon	3 months		6 months		9 months		12 months	
			pH	Ex-Ca m.e. %	pH	Ex-Ca m.e. %	pH	Ex-Ca m.e. %	pH	Ex-Ca m.e. %
Control	...									
Algerian rock phosphate	A	4.5900	9.70	4.50	9.20	5.66	9.00	6.00	8.80	6.40
"	B	4.5900	9.30	6.80	8.70	7.50	8.20	7.87	7.70	8.43
"	C	4.5900	9.40	6.72	8.85	7.13	8.40	7.60	7.90	8.30
"	D ₁	4.5900	9.40	6.72	8.80	7.13	8.30	7.67	7.85	8.25
"	D ₂	4.6900	9.50	6.51	8.85	7.13	8.50	7.50	7.90	8.00
"		4.5900	9.50	6.53	8.90	7.07	8.55	7.53	7.90	8.00
Raw bone meal	1	4.5900	9.20	6.80	8.60	7.49	8.00	8.05	7.65	8.43
Algerian rock phosphate	A	4.5900	8.80	7.20	8.45	7.85	8.00	7.93	7.65	9.05
"	B	4.5900	9.10	6.80	8.70	7.67	8.30	7.82	7.90	8.85
"	C	4.5900	8.95	6.92	8.60	7.68	8.20	7.60	7.80	8.90
"	D ₁	4.5900	9.30	6.41	8.75	7.31	8.40	7.57	7.90	8.85
"	D ₂	4.5900	9.40	6.50	8.80	7.20	8.50	7.57	7.90	8.85
Raw bone meal	2	4.5900	9.70	7.20	8.30	8.03	7.70	8.82	7.60	9.05

TABLE 7

Oxidation of Carbon during reclamation

200 gms soil + 5 gms of Wheat straw

Amendments		Amendment added in gms	% carbon	Carbon left after oxidation after			
				3 months	6 months	9 months	12 months
Control		...	1.2400	0.8580	0.7841	0.6633	0.5401
Algerian rock phosphate	A	1	1.2400	0.8485	0.7722	0.6523	0.5331
"	B	1	1.2400	0.8493	0.7785	0.6583	0.5352
"	C	1	1.2400	0.8493	0.7785	0.6578	0.5352
"	D ₁	1	1.2400	0.8510	0.7802	0.6590	0.5390
"	D ₂	1	1.2400	0.8510	0.7831	0.6590	0.5372
Raw bone meal		1	1.2400	0.8443	0.7612	0.6431	0.5125
Algerian rock phosphate	A	2	1.2400	0.8291	0.7558	0.6265	0.5210
"	B	2	1.2400	0.8325	0.7613	0.6301	0.5375
"	C	2	1.2400	0.8307	0.7598	0.6276	0.5289
"	D ₁	2	1.2400	0.8373	0.7695	0.6455	0.5390
"	D ₂	2	1.2400	0.8373	0.7721	0.6435	0.5375
Raw bone meal		2	1.2400	0.8253	0.7478	0.6218	0.5031

TABLE 8

Oxidation of carbon during reclamation
200 gms of soil \pm 10 gms of Wheat straw

Amendments	Amendment added in gms	% carbon	Carbon left after oxidation after			
			3 months	6 months	9 months	12 months
Control	...	2.4700	1.6300	1.4190	1.2101	1.0295
Algerian rock phosphate	A	2.4700	1.6152	1.3901	1.1901	1.0152
"	B	2.4700	1.6239	1.3952	1.1972	1.0201
"	C	2.4700	1.6201	1.3952	1.1935	1.0167
"	D ₁	2.4700	1.6288	1.4001	1.2001	1.0203
"	D ₂	2.4700	1.6258	1.4001	1.1972	1.0224
Raw bone meal	1	2.4700	1.6050	1.3860	1.1851	1.0051
Algerian rock phosphate	A	2.4700	1.5751	1.3357	1.1293	0.9554
"	B	2.4700	1.5801	1.3463	1.1408	0.9565
"	C	2.4700	1.5891	1.3412	1.1364	0.9553
"	D ₁	2.4700	1.5924	1.3567	1.1556	0.9608
"	D ₂	2.4700	1.5863	1.3502	1.1483	0.9680
Raw bone meal	2	2.4700	1.5700	1.3326	1.1230	0.9470

TABLE 9

Oxidation of Carbon during reclamation
200 gms of soil \pm 20 gms of Wheat straw

Amendments	Amendment added in gms	% Carbon	Carbon left after oxidation after		
			3 months	6 months	9 months 12 months
Control	...	4.5900	2.9800	2.7050	2.4153 2.2032
Algerian rock phosphate	A	4.5900	2.9493	2.6183	2.3304 2.0283
"	B	4.5900	2.9640	2.6405	2.3597 2.0751
"	C	4.5900	2.9574	2.6289	2.3424 2.0421
"	D ₁	4.5900	2.9754	2.6588	2.3852 2.1352
"	D ₂	4.5900	2.9700	2.6485	2.3705 2.1103
Raw bone meal	1	4.5900	2.9410	2.6035	2.3152 2.0035
Algerian rock phosphate	A	4.5900	2.8503	2.4257	2.0858 1.8100
"	B	4.5900	2.8698	2.4557	2.1153 1.8407
"	C	4.5900	2.8621	2.4408	2.1005 1.8253
"	D ₁	4.5900	2.8895	2.4856	2.1556 1.9643
"	D ₂	4.5900	2.8788	2.4705	2.1323 1.8320
Raw bone meal	2	4.5900	2.8460	2.4157	2.0725 1.7865

TABLE 10

Status of available phosphate during reclamation

200 gms of soil + 5 gms of Wheat straw

Amendments	Amendment added in gms	% carbon	Available phosphate		
			in the system in %	3 months	5 months 9 months 12 months
Control	...	1.2400	0.0318	0.0392	0.0411 0.0429
Algerian rock phosphate	A	1.2400	0.0693	0.0964	0.1019 0.1049
"	B	1.2400	0.0599	0.0748	0.0847 0.0866
"	C	1.2400	0.0650	0.0819	0.0934 0.0959
"	D ₁	1.2400	0.0443	0.0571	0.0641 0.0656
"	D ₂	1.2400	0.0472	0.0571	0.0637 0.0652
Raw bone meal	1	1.2400	0.0623	0.0901	0.1041 0.1071
Algerian rock phosphate	A	1.2400	0.1075	0.1343	0.1424 0.1509
"	B	1.2400	0.0860	0.1073	0.1193 0.1213
"	C	1.2400	0.0932	0.1207	0.1297 0.1345
"	D ₁	1.2400	0.0719	0.0743	0.0824 0.0899
"	D ₂	1.2400	0.0827	0.0730	0.0827 0.0874
Raw bone meal	2	1.2400	0.1013	0.1343	0.1513 0.1563

TABLE II

Status of available phosphate during reclamation
200 gms of soil + 10 gms of Wheat straw

Amendments	Amendment added in gms	% carbon	Available phosphate in the system in %	Available phosphate in % after 3 months 6 months 9 months 12 months
Control	...	2.4700	0.0318	0.0363 0.0391 0.0416 0.0432
Algerian rock phosphate	A	2.4700	0.0696	0.0918 0.0997 0.1052 0.1083
"	B	2.4700	0.0599	0.0758 0.0824 0.0867 0.0885
"	C	2.4700	0.0650	0.0825 0.0896 0.0948 0.0973
"	D ₁	2.4700	0.0468	0.0594 0.0643 0.0668 0.0683
"	D ₂	2.4700	0.0472	0.0597 0.0648 0.0669 0.0684
Raw bone meal	1	2.4700	0.0668	0.0935 0.1036 0.1095 0.1136
Algerian rock phosphate	A	2.4700	0.1075	0.1383 0.1484 0.1549 0.1589
"	B	2.4700	0.0880	0.1110 0.1203 0.1255 0.1294
"	C	2.4700	0.0982	0.1090 0.1196 0.1255 0.1293
"	D ₁	2.4700	0.0619	0.0767 0.0859 0.0919 0.0954
"	D ₂	2.4700	0.0627	0.0764 0.0829 0.0854 0.0876
Raw bone meal	2	2.4700	0.1018	0.1381 0.1406 0.1481 0.1532

TABLE 12

Status of available phosphate during reclamation
200 gms of soil \div 20 gms of Wheat straw

Amendments	Amendment added in gms	% carbon	Available phosphate in the system in %	Available phosphate in % after 3 months 6 months 9 months 12 months
Control	...	4.5900	0.0318	0.0381 0.0410 0.0425 0.0439
Algerian rock phosphate	A	4.5900	0.0590	0.0989 0.1096 0.1132 0.1167
"	B	4.5900	0.0599	0.0809 0.0887 0.0936 0.0965
"	C	4.5900	0.0630	0.0884 0.0965 0.1026 0.1061
"	D ₁	4.5900	0.0468	0.0645 0.0906 0.0941 0.0766
"	D ₂	4.5900	0.0472	0.0647 0.0706 0.0737 0.0762
Raw bone meal	1	4.5900	0.0560	0.1048 0.1128 0.1178 0.1218
Algerian rock phosphate	A	4.5900	0.1076	0.1431 0.1543 0.1618 0.1678
"	B	4.5900	0.0889	0.1205 0.1304 0.1369 0.1404
"	C	4.5900	0.0932	0.1195 0.1304 0.1379 0.1429
"	D ₁	4.5900	0.0619	0.0832 0.0935 0.1007 0.1052
"	D ₂	4.5900	0.0527	0.0854 0.0929 0.0984 0.1019
Raw bone meal	2	4.5900	0.1018	0.1403 0.1538 0.1623 0.1683

The following observations of Dhar¹¹ are of great interest in this connection :—

“The third dissociation constant of phosphoric acid is smaller than the first and second dissociation constants of carbonic acid and hence carbonic acid converts tricalcium phosphate into dicalcium phosphate which is more soluble than tricalcium phosphate. Thus the availability of phosphates is increased in the soil richer in carbonic acid obtained from the oxidation of organic substances. Similarly nitrous acid and nitric acid formed in the ammonification and nitrification of proteins make phosphates more readily soluble. Thus phosphates are more useful in presence of organic substances like farm manure, straw, etc., undergoing slow oxidation.”

Baur¹², Ramasawami Sivan¹³ and Rahn¹⁴ reported that organic matter increases the availability of added phosphates during its decomposition.

The exchangeable calcium of the system is greatly increased when different phosphates in conjunction with wheat straw are added to alkali soil. This increase in the exchangeable calcium may be ascribed to the dissolving power of carbonic acid and other weak acids liberated during the decomposition of organic matter on calcium carbonate present in bone meal and in rock phosphates. $\text{Ca}_3(\text{PO}_4)_2$ present in the rock phosphate and bone meal also releases Ca^{++} by the action of carbon dioxide. Thus the soluble Ca^{++} ion replaces Na^+ ion from the exchange complex of alkali soil thereby increasing the exchangeable calcium status of the system.

The results clearly show that incorporation of insoluble phosphates with wheat straw produces better effect in lowering the pH and increasing the exchangeable calcium of alkali soil than with wheat straw alone. The order of efficiency of different phosphates in the reclamation of alkali soil is as follows :—

Bone meal > A > C > B > D_1 > D_2

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